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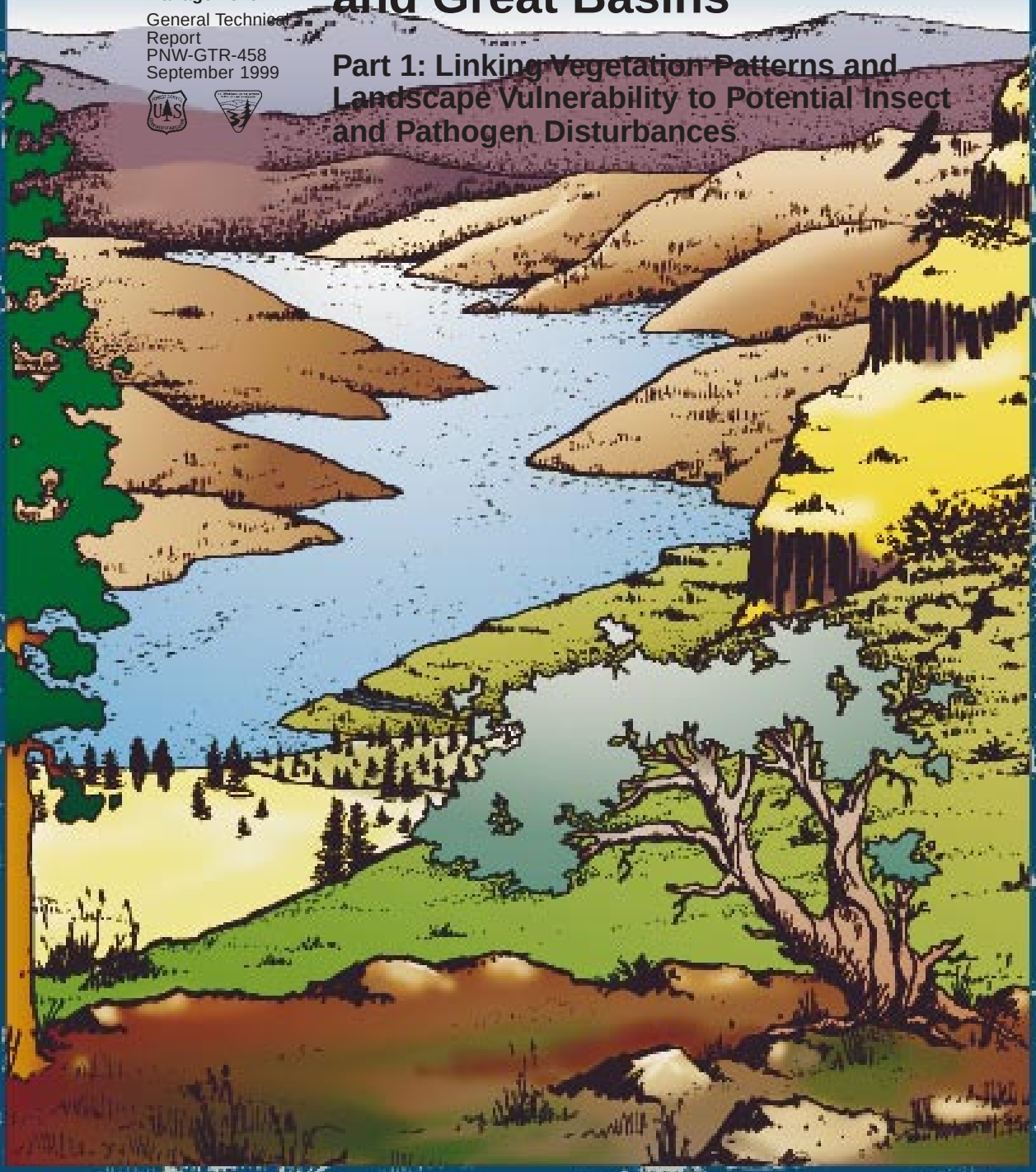
Historical and Current Forest and Range Landscapes in the Interior Columbia River Basin and Portions of the Klamath and Great Basins

Part 1: Linking Vegetation Patterns and Landscape Vulnerability to Potential Insect and Pathogen Disturbances



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Historical and Current Forest and Range Landscapes in the Interior Columbia River Basin and Portions of the Klamath and Great Basins

Part 1: Linking Vegetation Patterns and Landscape Vulnerability to Potential Insect and Pathogen Disturbances

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Interior Columbia Basin Ecosystem Management Project: Scientific Assessment

Thomas M. Quigley, Editor

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Abstract

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Management activities of the 20th century, especially fire exclusion, timber harvest, and domestic livestock grazing, have significantly modified vegetation spatial patterns of forests and ranges in the interior Columbia basin. Compositional patterns as well as patterns of living and dead structure have changed. Dramatic change in vital ecosystem processes such as fire, insect, and pathogen disturbances, succession, and plant and animal migration is linked to recent change in vegetation patterns. Recent change in vegetation patterns is also a primary reason for current low viability and threatened, endangered, or sensitive status of numerous native plant and animal species. Although well intentioned, 20th-century management practices have not accounted for the larger patterns of living and dead vegetation that enable forest ecosystems to function in perpetuity and maintain their structure and organization through time, or for the disturbances that create and maintain them. Knowledge of change in vegetation patterns enhances resource manager and public awareness of patterns that better correspond with current climate, site conditions, and native disturbance regimes, and improves understanding of conditions to which native terrestrial species have already adapted.

In this study, we characterized recent historical and current vegetation composition and structure of 337 randomly sampled subwatersheds (9500 ha average size), in 43 of 164 total subbasins (404 000 ha average size), selected by stratified random draw on all ownerships within the interior Columbia River basin and portions of the Klamath and Great Basins (collectively referred to as the basin). We compared landscape patterns, vegetation structure and composition, and landscape vulnerability to 21 major insect and pathogen disturbances of historical and current vegetation coverages. For each selected subwatershed, we constructed historical and current vegetation maps from interpretations of 1932-66 and 1981-93 aerial photos, respectively. Areas with homogeneous vegetation composition and structure were delineated as patches to a minimum size of 4 ha. We then attributed cover types (composition), structural classes (structure), and series-level potential vegetation types (site potential) to individual patches within subwatersheds by modeling procedures. We characterized change in vegetation spatial patterns by using an array of class and landscape pattern metrics and a spatial pattern analysis program. Finally, we translated change in vegetation patterns to change in landscape vulnerability to major forest pathogen and insect disturbances. Change analyses results were reported for province-scale ecological reporting units.

Forest and range ecosystems are significantly altered after their first century of active management, but there is reason for guarded optimism. Large areas remain relatively unchanged and intact, such as can be found on the east side of the Cascade Range in Washington and in the central Idaho mountains, and these areas may provide an essential “nucleus” for conservation strategies and ecosystem restoration. Strategies for improving the health of basin ecosystems can build on existing strengths. Improved understanding of change in vegetation patterns, causative factors, and links with disturbance processes will assist managers and policymakers in making informed decisions about how to address important ecosystem health issues.

Keywords: Landscape characterization, ecological assessment, vegetation patterns, interior Columbia River basin, Klamath Basin, Great Basin, ecosystem health, vegetation pattern-disturbance process interactions, insect and disease disturbance, landscape ecology, ecosystem processes, potential natural vegetation modeling, vegetation change, fire effects.

Preface

The Interior Columbia Basin Ecosystem Management Project (ICBEMP) was initiated by the Forest Service and the Bureau of Land Management to respond to several critical issues including, but not limited to, forest and rangeland health, anadromous fish concerns, terrestrial species viability concerns, and the recent decline in traditional commodity flows. The charter given to the project was to develop a scientifically sound, ecosystem-based strategy for managing the lands of the interior Columbia River basin administered by the Forest Service and the Bureau of Land Management.

The Science Integration Team was organized to develop a framework for ecosystem management, a broad-scale assessment of the socioeconomic and biophysical systems in the basin, and an evaluation of alternative management strategies. The broad-scale assessment of the biophysical systems consisted of two parts: (1) a multiscale characterization of biophysical environments of the basin (Jensen and others 1997), and (2) a broad-scale landscape assessment of change in vegetation patterns and disturbance regimes of the basin (Hann and others 1997). In addition to the broad-scale landscape assessment, a midscale assessment was conducted to validate the results of the broad-scale assessment at a scale appropriate to observing the vegetation pattern-disturbance process interactions. This paper is one of a series of four papers developed to document the results of that mid-scale assessment.

The Science Integration Team, although organized functionally, worked hard at integrating the research approaches, analyses, and conclusions. It was the collective effort of the team that provided depth and understanding to the work of the project. The Science Integration Team leadership included deputy team leaders Russel Graham and Sylvia Arbelbide; landscape ecology—Wendel Hann, Paul Hessburg, and Mark Jensen; aquatic—Jim Sedell, Kris Lee, Danny Lee, Jack Williams, Lynn Decker; economic—Richard Haynes, Amy Horne, and Nick Reyna; social science—Jim Burchfield, Steve McCool, and Jon Bumstead; terrestrial—Bruce Marcot, Kurt Nelson, John Lehmkuhl, Richard Holthausen, and Randy Hickenbottom; and broad-scale spatial analysis—Becky Gravenmier, John Steffenson, and Andy Wilson.

Thomas M. Quigley
Editor

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Interior Columbia Basin Ecosystem Management Project

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Summary

In this midscale assessment, we have quantified change in vegetation patterns and landscape vulnerability to fire, insect, and pathogen disturbances over the most recent 50 to 60 years based on a stratified random sample of 337 subwatersheds (9500 ha average size) distributed in 43 subbasins (404 000 ha average size), on all public and private ownerships within the interior Columbia River basin (the basin). Change analyses results were reported by province-scale ecological reporting units (ERUs). In the assessment, we have compared landscape patterns, structure, composition, and vulnerability to insect and pathogen disturbances of historical and current vegetation coverages. Forest and rangeland vegetation composition and structure were remotely sensed from resource aerial photographs taken from 1932 to 1966 (historical), and from 1981 to 1993 (current). Areas with homogeneous vegetation composition and structure were delineated as patches, with a minimum patch size of 4 ha. Cover types, structural classes, and potential vegetation types (PVTs) were modeled for each forest or range patch by using raw photointerpreted attributes and topographic or biophysical data from other digital sources of comparable scale and image resolution.

Each patch was assigned a vulnerability rating for three to seven vulnerability factors associated with each of 21 different potential forest insect and pathogen disturbances: one defoliator disturbance, seven bark beetle disturbances, four dwarf mistletoe disturbances, six root disease disturbances, two rust disturbances, and one stem decay disturbance. Patch vulnerability factors were taken from the published literature or were based on the expert opinions and experiences of field pathologists and entomologists with regional or localized experience in specific geographic areas. Vulnerability factors were unique for each host-pathogen or host-insect interaction modeled and included such items as site quality (differences in site potential), host abundance, canopy layers, host age or host size, stand vigor, stand density, connectivity of host patches, topographic setting, and type of visible logging disturbance.

Vegetation maps, patch attributes, and derived cover type, structural class, and PVT attributes formed the basic data set from which all subsequent pattern analyses were accomplished. Individual patches were described by their composition, structure, and PVT from selected photointerpreted attributes. We used percentage of area, mean patch size, and patch density metrics to describe changes in area and connectivity of patch types in subwatersheds of an ERU. Change from historical to current conditions was estimated as the mean difference between historical and current conditions, not as the percentage of change from historical conditions, to avoid the bias of establishing the historical condition as an essential reference. For each ERU, means, mean standard errors, and confidence intervals were estimated by using methods for simple random samples with subwatersheds as sample units. Statistically significant ($P \leq 0.2$) change was determined by examining the 80-percent confidence interval around the mean difference for the ERU.

We supplemented this statistical test with two additional analyses that enabled us to evaluate the potential ecological significance of patch type change in area or connectivity of area. First, we approximated the historical range of variation by calculating the historical sample median 75-percent range for each metric, and we compared the current sample median value with this estimate of the historical range. Second, we characterized the most significant changes in absolute area of a patch type within a sample by using transition analysis. Ecologically significant change was ultimately determined after examining each of the three pieces of information.

Physiognomic Types

Forest cover increased in the Blue Mountains, Columbia Plateau, Southern Cascades, and Upper Snake ERUs, where our results suggested that effective fire prevention, suppression, and exclusion resulted in expansion of forests into areas that previously were bare ground or shrubland or into former herbland areas previously maintained by fire or created by early logging.

Forest cover declined in the Upper Klamath ERU, and our analysis indicated that timber harvest activities during the sample period caused the observed depletion of forest area. Connectivity of forests increased in the Central Idaho Mountains and Upper Snake ERUs. The Central Idaho Mountains ERU contains large areas of congressionally or administratively designated wilderness or roadless areas, and it is likely that increased connectivity occurred as a result of fire exclusion. Connectivity of forests declined significantly in the Upper Klamath ERU where evidence of timber harvest was widespread. Forests of the Upper Klamath are naturally quite fragmented. Forested slopes often are separated by broad grassy valley bottoms and dry southerly aspects. Timber harvest apparently accentuated this characteristic.

Woodland area increased in the Blue Mountains, Columbia Plateau, Northern Cascades, Northern Great Basin, Owyhee Uplands, Snake Headwaters, and Upper Klamath ERUs and declined in no ERUs, thereby suggesting that fire suppression, fire exclusion, and grazing enabled expansion at the expense of declining herblands and shrublands. Perhaps most dramatic of all changes in physiognomic conditions was the across-the-board regional decline in area of shrublands. Shrubland area declined in all ERUs but the Southern Cascades, which had little to begin with. Ecologically significant reduction was observed in the Blue Mountains, Central Idaho Mountains, Columbia Plateau, Northern Great Basin, Owyhee Uplands, and Snake Headwaters ERUs, and no ERU exhibited increased shrubland area. Transition analyses indicated that losses to native shrublands resulted from various factors, including forest or woodland expansion as observed in the Blue Mountains and Northern Great Basin ERUs, cropland expansion as observed in the Northern Great Basin ERU, and conversion to seminative or nonnative herbland as observed in the Owyhee Uplands or Snake Headwaters ERU.

Herbland area increased significantly in the Central Idaho Mountains, Northern Great Basin, Owyhee Uplands, Snake Headwaters, and Southern Cascades ERUs and did not decline in any ERU. In the Central Idaho Mountains, herbland area increased by about 1 percent, and increases were primarily to colline and montane bunchgrass cover types. But in the Northern Great Basin, herbland area rose at the expense of shrublands; historical shrubland area fell by more than 15 percent of the land area of the ERU. Half of the lost shrubland area is currently occupied by juniper woodland, and the balance of the area currently supports montane bunchgrasses or exotic grass and forb cover. Herbland and shrubland area followed a similar pattern in the Owyhee Uplands. Across the basin, most increase in herbland area was the result of expanding colline exotic grass and forb cover with the conversion of shrublands.

Forest and Range Cover Types

Predicted shifts from early seral forest species, such as ponderosa pine, western larch, lodgepole pine, western white pine, and sugar pine, to late seral species, such as grand fir, white fir, subalpine fir, Engelmann spruce, and western hemlock, were evident in several ERUs. In some, the shift from seral to late seral climax species was at least partially masked by steep climatic gradients. For example, in the Northern Cascades ERU, Douglas-fir is seral in subalpine fir, western hemlock, and Pacific silver fir PVTs but to the east is climax or late seral in the Douglas-fir PVT.

Of all forested ERUs, the most pronounced shifts from early to late seral cover types occurred in the Northern Glaciated Mountains. Western larch cover declined significantly in the Central Idaho Mountains, Columbia Plateau, and Northern Glaciated Mountains ERUs, and ponderosa pine cover decreased in the Northern Cascades, Northern Glaciated Mountains, Upper Clark Fork, and Upper Klamath ERUs. Ponderosa pine cover increased in the Southern Cascades as a result of regrowth of forests clearcut just before the period of our historical photo coverage. Lodgepole pine cover declined in the Snake Headwaters ERU, and in six other ERUs. Western white pine cover decreased in the Northern Glaciated Mountains ERU as a consequence of white pine blister rust, mountain pine beetle mortality, and selective harvesting and increased slightly in the Northern Cascades as a result of recent reforestation efforts. Whitebark pine-subalpine larch cover declined in the Central Idaho Mountains, Northern

Glaciated Mountains, Snake Headwaters, and Upper Clark Fork ERUs and increased in the Blue Mountains and Northern Cascades ERUs. Decline in whitebark pine cover likely was the result of ongoing blister rust and mountain pine beetle mortality.

In contrast, Douglas-fir cover increased significantly in the Blue Mountains, Columbia Plateau, and Northern Cascades ERUs; grand fir-white fir cover increased in the Northern Cascades and Northern Glaciated Mountains; Pacific silver fir cover increased in the Northern Cascades ERU; Engelmann spruce-subalpine fir cover increased in the Northern Glaciated Mountains, Snake Headwaters, Southern Cascades, and Upper Clark Fork ERUs; and western hemlock-western redcedar cover increased in the Columbia Plateau, and Northern Glaciated Mountains ERUs. Engelmann spruce-subalpine fir cover declined significantly in the Blue Mountains, and Engelmann spruce-subalpine fir and western hemlock-western redcedar cover both decreased in the Northern Cascades. We believe the noted increases in shade-tolerant cover types are the direct result of effective fire suppression and exclusion and selective timber harvest.

Among woodland cover types, juniper cover significantly increased in the Blue Mountains, Columbia Plateau, Northern Great Basin, Owyhee Uplands, Snake Headwaters, and Upper Klamath ERUs and decreased in no ERU where it was a major cover type. Oregon white oak cover increased in the Northern Cascades ERU. Fire exclusion and grazing may be primary causes of the observed increases, but we were unable to test this hypothesis directly.

Significant reductions in shrubland cover types were noted in virtually every ERU, but effects were most dramatic where shrublands accounted for more than one-quarter of the land area of an ERU. The largest reductions in shrub cover types occurred in the Columbia Plateau, Northern Great Basin, Owyhee Uplands, and Upper Snake ERUs. Significant declines in shrub cover types also were observed in the Blue Mountains, Snake Headwaters, and Upper Klamath ERUs. In general, the greatest losses to shrublands were associated with forest or woodland expansion as observed in the Blue Mountains and Northern Great Basin ERUs, cropland expansion as observed in the Northern Great Basin ERU, and conversion to seminative or nonnative herbland as observed in the Owyhee Uplands or Snake Headwaters ERUs. Most shrubland cover in the Blue Mountains, Columbia Plateau, Owyhee Uplands, and Upper Snake ERUs resides below lower treeline, and in each case, the most significant losses of shrub cover occurred in these colline settings. Shrublands of the Northern Great Basin, Snake Headwaters, and Upper Klamath primarily occupy montane settings. Cover types of these elevation settings suffered the greatest losses.

In general, herbland cover increased throughout the basin as a result of declining shrubland area, but several important cover type losses also were noteworthy. Bunchgrass cover declined significantly in several ERUs, notably the Columbia Plateau, Northern Cascades, Northern Glaciated Mountains, Upper Clark Fork, and Upper Klamath. Bunchgrass cover increased in the Central Idaho Mountains, Northern Great Basin, Snake Headwaters, and Upper Snake ERUs. Exotic grass and forb cover increased in 9 of 13 ERUs. Significant increases in exotics in either colline or montane settings occurred in the Blue Mountains, Columbia Plateau, Northern Cascades, Northern Great Basin, Owyhee Uplands, Snake Headwaters, and Upper Clark Fork ERUs. Ecological reporting units most affected by expansion of exotics were, in ascending order, the Columbia Plateau, Northern Great Basin, and Owyhee Uplands. Finally, postlogging grass-forb cover increased in all forested ERUs.

Cropland area increased dramatically in two ERUs, the Upper Klamath and the Upper Snake. Cropland area declined in the Blue Mountains. Area in irrigated pastures increased in several ERUs, but only the increase observed in the Northern Glaciated Mountains was significant. Urban and rural developed area increased in half of the ERUs during the sample period; the increase was significant in the Central Idaho Mountains, Northern Cascades, Southern Cascades, and Upper Snake ERUs.

Forest and Range Structural Classes

In general, the structure of current forests of sampled ERUs was simpler when compared with historical forests, but causal links with management are difficult to establish because the amount of fire suppression or total timber harvest, for instance, was not directly measurable or quantifiable. Still, structural changes observed were consistent with management activities implicated as primary factors in the overall simplification of structural complexity of basin forests: namely, timber harvest, fire suppression, fire exclusion, and domestic livestock grazing. In future work, we will compute landscape metrics by using structural classes as patch types to further quantify patterns of structural change.

Area in forest stand-initiation structures declined significantly in four of nine forest-dominated ERUs and increased significantly in one, the Blue Mountains. Area in stand-initiation structures declined in the Central Idaho Mountains, Lower Clark Fork, Northern Glaciated Mountains, and Upper Clark Fork ERUs. Area in old-forest structures declined in most forested ERUs, but the most significant declines occurred in the Blue Mountains, Northern Cascades, Snake Headwaters, and Upper Klamath ERUs. In general, area in intermediate (not new and not old forest) structural classes (stem exclusion, understory reinitiation, and young multistory) increased in most forested ERUs; the most notable increases occurred in the Blue Mountains, Central Idaho Mountains, Columbia Plateau, Lower Clark Fork, Northern Glaciated Mountains, Snake Headwaters, Southern Cascades, and Upper Clark Fork ERUs. Area in intermediate structural classes actually declined in the Upper Klamath ERU, where most evidence suggested extensive past harvesting.

Area of open or closed shrub structure declined in every ERU where the shrubland physiognomic type comprised more than 0.5 percent of the area. The most significant loss of shrub structure in the basin was the loss of open low-medium structures (primarily sagebrushes, rabbitbrush, and bitterbrush). Significant reductions in open low-medium shrub structures were noted in the Blue Mountains, Columbia Plateau, Northern Great Basin, Owyhee Uplands, and Snake Headwaters ERUs. Significant reduction in closed low-medium shrub structure was noted in the Columbia Plateau ERU. Open herbland area increased in most ERUs where significant reduction in open low-medium shrub structure occurred. We speculate that range management activities to improve forage production for domestic livestock were responsible for much of the noted change.

Forest Vulnerability to Insect and Pathogen Disturbances

Forest landscapes have changed significantly in their vulnerability to major insect and pathogen disturbances. Changes have occurred in response to management practices common in the 20th century. Management practices have significantly increased vulnerabilities in some subbasins and ERUs, and decreased them in others. Vulnerability changes at the ERU scale often were insignificant or masked owing to high variation among sampled subwatersheds. High variability among subwatersheds within ERUs was a function of large geographic extent, high variability in vegetative communities and biophysical conditions, and variable climatic and disturbance regimes. We learned that analysis of change in vulnerability to various pathogen and insect disturbances is best accomplished at a subwatershed scale, given change among similar subwatersheds at a subregional scale.

Change analyses indicated that forests of the Blue Mountains ERU were influenced quite predictably by timber harvesting, fire suppression and exclusion, and livestock grazing. Timber harvest minimized old-forest area and area with remnant large trees to a fraction of the historical area and reduced the availability of medium and large trees in all structures. Medium and large trees were harvested from all major cover types including ponderosa pine, grand fir-white fir, Engelmann spruce-subalpine fir, and Douglas-fir. In the absence of frequent fires and under the influence of selective harvesting and grazing, Douglas-fir cover expanded, forest structures became more layered, grass and shrub understories were replaced by conifer understories, and forests and woodlands expanded in areas that were formerly grasslands and shrublands.

In the Blue Mountains, area vulnerable to western spruce budworm did not change significantly; a relatively large proportion of the ERU was vulnerable in the historical coverage, and a similar proportion is vulnerable in the existing condition. But were defoliation to occur under existing conditions, growth and mortality effects likely would be more pronounced. Area vulnerable to Douglas-fir beetle has increased because Blue Mountains landscapes in the existing condition have increased cover, connectivity, size of Douglas-fir, and stand densities. Area vulnerable to western pine beetle (type 1) disturbance of mature and old ponderosa pine fell because medium and large ponderosa pine were selectively harvested from old and other forest structures. Area vulnerable to mountain pine beetle (type 1) disturbance of lodgepole pine declined as a result of declining area where lodgepole pine occurs as a major seral species in mixed types. Area vulnerable to fir engraver and spruce beetle disturbance also declined as a result of timber harvest, extended drought, and bark beetle outbreaks.

Area vulnerable to Douglas-fir dwarf mistletoe increased with expanded area of Douglas-fir and increased canopy layering and contiguity of host patches. In contrast, area vulnerable to ponderosa pine and western larch dwarf mistletoes declined as a result of reduced area of ponderosa pine and western larch overstory cover. Even with declining area of grand fir, white fir, and subalpine fir overstory cover, area vulnerable to S-group annosum root disease likely increased. We believe this is true because the total area occupied by host species increased (but hosts now more often occur in intermediate and lower crown classes), a large percentage of the total forest area has been entered for timber harvest, and freshly cut stumps provide avenues for spread of this disease to new patches. Area and connectivity of area vulnerable to laminated root rot disturbance increased primarily as a result of increased cover and connectivity of Douglas-fir patches, but also as a result of increased area occupied by true firs.

Few significant changes in vulnerability were in evidence in the Central Idaho Mountains. For the most part, vulnerability characterizations indicated that the primary management influence during the sample period was exclusion of fire. Shade-tolerant true firs increased slightly in area and dominance, and insects and pathogens that specialize in attacking true firs were modestly favored by that increase. Area vulnerable to western spruce budworm increased but the change was not significant; a large proportion of the ERU area (49.4 percent) was highly vulnerable in the historical coverage, and a similar proportion (51.1 percent) is vulnerable in the existing condition. Area vulnerable to fir engraver and S-group annosum root disease disturbance also increased.

Our analyses suggested that dry and mesic forests of the Columbia Plateau have been influenced in a predictable manner by selective harvesting, fire suppression, and fire exclusion. Area highly vulnerable to western spruce budworm disturbance increased during the sample period; increased vulnerability was associated with increased area of Douglas-fir cover and increased area of Douglas-fir and grand fir in multilayered understories, both predicted consequences of fire exclusion and selective harvesting. Selective harvesting reduced area in old-forest structures and reduced the abundance of medium and large trees in all structures. Consequently, we observed a modest decline in vulnerability to western pine beetle (type 1) disturbance of mature and old ponderosa pine. Area vulnerable to western pine beetle (type 2) and mountain pine beetle (type 2) disturbance of immature, high-density ponderosa pine increased during the sample period as a result of expanded area of ponderosa pine cover in young multistory structures. Area highly vulnerable to fir engraver increased as a result of increased area with grand fir understories. Area highly vulnerable to S-group annosum also increased because grand fir and western hemlock in mixed species cover types, and occurring as understory species, increased during the sample period, as did area in these types with visible logging entry. Area vulnerable to white pine blister rust (type 1) disturbance of western white pine declined; decline was likely the result of white pine blister rust and mountain pine beetle mortality and selective harvesting.

Analysis of cover type and structural class changes and vulnerability characterizations indicate that significant harvesting has occurred in highly productive forests of the Lower Clark Fork ERU, but fire exclusion perhaps has had the greatest effect on conditions we observe today. In our small sample, area with medium and large trees increased during the sample period, and area in the 90- to 100- percent crown cover class and in multilayered canopies increased. Each change is a predictable consequence of fire suppression and exclusion, especially in an area where stand-replacing fire historically played such a significant role.

Area vulnerable to western spruce budworm increased but the change was not significant; a large proportion of the ERU (56.8 percent) was highly vulnerable in the historical condition, and a similar proportion (65 percent) is vulnerable in the existing condition. The 8.2-percent increase was not statistically significant because of the small sample size; further sampling is needed to establish the trend. In the absence of fire, lodgepole pine-dominated landscapes of the Lower Clark Fork aged and became more synchronous in their vulnerability to bark beetle and fire disturbances. With increased overstory and understory grand fir cover developing during the sample period, vulnerability to fir engraver disturbance also increased, but the 8.7-percent increase again was not statistically significant because of our small sample size. Similarly, area vulnerable to *Armillaria* root disease increased, but the change was not significant.

Results of vulnerability characterizations for the Northern Cascades ERU indicated that the primary effect of management during the sample period was probably timber harvest followed by fire suppression and exclusion. Area occupied by old-forest structures and medium and large trees declined significantly during the sample period, as did area of ponderosa pine cover. Area of Douglas-fir cover increased, but area of medium and large Douglas-fir declined. These results explain much of the change we observed in vulnerability to pathogen and insect disturbances. Vulnerabilities to western pine beetle (type 1) disturbance of mature and old ponderosa pine and Douglas-fir beetle disturbance both declined with the loss of medium and large hosts. Connectivity of vulnerable areas also declined, indicating that remaining distributions of medium and large ponderosa pine and Douglas-fir are relatively fragmented.

Area and connectivity of area vulnerable to western pine beetle (type 2) and mountain pine beetle (type 2) disturbance of immature, high-density ponderosa pine also declined owing to reduced area of ponderosa pine cover in young and middle-aged structures. Area vulnerable to western (ponderosa pine) dwarf mistletoe disturbance declined with the loss of ponderosa pine overstories through harvesting. In contrast, area vulnerable to S-group annosum root disease disturbance increased during the sample period. The observed increase in high-vulnerability area was associated with increased area and stature of grand fir and Pacific silver fir cover and increased area with visible logging entry.

Fire exclusion and timber harvest acted together to produce the changes in vulnerability we observed in the Northern Glaciated Mountains ERU. In our historical vegetation coverage, no visible logging entry was apparent for 91 percent of the forested area. In the current condition, signs of visible logging activity were apparent for 26 percent of that area. But old-forest area and area with remnant large trees did not decline during the sample period. Furthermore, area occupied by medium and large trees actually increased. We speculate that because stand-replacing fires once were common in the ERU, regrowth of forest in the absence of fire apparently offset some of the effects of harvesting at the ERU scale. Predicted effects of fire exclusion also were observed: increased crown cover, increased canopy layering, and increased cover by shade-tolerant understory conifers.

Area vulnerable to western spruce budworm increased with increasing cover of grand fir and subalpine fir and increased canopy layering. In the absence of fire, lodgepole pine-dominated landscapes of the Northern Glaciated Mountains became more synchronous in their vulnerability to mountain pine beetle and fire disturbances. Area and connectivity of area vulnerable to spruce beetle disturbance increased with increased area and stature of spruce in the Engelmann spruce-subalpine fir cover type. As expected, area vulnerable to ponderosa pine and western larch dwarf mistletoes declined with the reduction of ponderosa

pine and western larch cover. Area vulnerable to *Armillaria* root disease and S-group annosum root disease increased with the increasing dominance of shade-tolerant overstories and understories; area and connectivity of area vulnerable to white pine blister rust (type 1) disturbance of western white pine declined as a result of white pine blister rust and mountain pine beetle mortality and selective harvesting.

Fire exclusion and, to a lesser extent, timber harvest interacted to produce the changes in vulnerability that we observed in the Snake Headwaters ERU. In the historical vegetation condition, no visible logging entry was apparent in any of the forested area. In the current condition, signs of visible current or past logging were apparent for 2 percent of the area. Old-forest area and area with remnant large trees declined during the sample period, but changes were not statistically significant. Area occupied by medium and large trees also declined. Overall, increased area with visible logging could not account for some of the changes in vulnerability we observed. Area and connectivity of area vulnerable to western spruce budworm disturbance increased dramatically during the sample period; increase was associated with increased area of Engelmann spruce-subalpine fir cover in multilayered structural arrangements. Area and connectivity of area vulnerable to Douglas-fir beetle disturbance also increased. Because total area in old-forest structures declined, most of the increased area likely was associated with increased abundance of Douglas-fir larger than 22.7 cm d.b.h. in structural classes other than old forest.

Area vulnerable to mountain pine beetle (type 1) disturbance of high-density lodgepole pine fell by 5.4 percent, and area of lodgepole pine cover declined by 4.3 percent. These results suggest that the area of small to medium lodgepole pine in both pure and mixed compositions declined during the sample period. We know that before and during the period of our sample, large areas of Snake Headwaters lodgepole pine forest were attacked and killed by the mountain pine beetle. But these results suggest that salvage and regeneration efforts influenced less than half of that area at best. Beetle disturbance and fire exclusion resulted in cover type conversion of some areas to Engelmann spruce and subalpine fir. These changes were corroborated by transition analyses. Area vulnerable to *Armillaria* root disease and S-group annosum root disease increased significantly with increasing dominance of shade-tolerant overstories and understories.

Analyses of vegetation change and characterizations of disturbance vulnerability indicated that the Southern Cascades have been influenced quite significantly and predictably by timber harvesting and fire exclusion. Area of old single-story and old multistory forest structures more than doubled during the sampling period, but area with remnant large trees associated with structures other than old forest declined, albeit nonsignificantly, by 42 percent. Area occupied by medium and large trees associated with all forest structures increased by 10 percent during the sample period. But average area in the forest physiognomic type also rose by 10 percent, mainly as a result of regrowth of large areas being clearcut harvested before our historical vegetation condition. We speculate that the large harvested area likely was dominated by patches with large ponderosa pine trees and old single-story structures.

In the Southern Cascades, area vulnerable to western spruce budworm disturbance increased; the increase was associated with increased area of multilayered, shade-tolerant understories. But area vulnerable to budworm disturbance amounts to little more than 10 percent of the area of the ERU, even in the existing condition. Area vulnerable to Douglas-fir beetle and Douglas-fir dwarf mistletoe disturbances declined because area and connectivity of patches with medium and large Douglas-fir in old forest and other structures declined. Area vulnerable to mountain pine beetle (type 1) disturbance of high-density lodgepole pine declined and area of the lodgepole pine cover remained unchanged. As was the case in the Blue Mountains, these results suggest that area of lodgepole pine in historically mixed compositions declined during the sample period as a result of mountain pine beetle outbreaks and the exclusion of regenerative fires. Area vulnerable to *Armillaria* root disease and laminated root rot disturbance increased with expanded area of subalpine fir, grand fir, and Douglas-fir in pure and mixed species compositions; expanded area of shade-tolerant understories; and increased crown cover of host species.

Forest vegetation of the Upper Clark Fork ERU has been radically altered by timber harvest and, to a lesser extent, fire suppression and exclusion. Most especially, the grain of Upper Clark Fork landscapes has been refined. In our historical vegetation coverage, 12 percent of the forest area exhibited remotely sensed visible signs of logging; in the existing condition, 37 percent of the forest area exhibited visible signs of logging. During the sample period, forest and woodland area affected by regeneration and selective harvesting jumped from 10 to 20 percent of the forest area. Overall, the level of timber harvest had little effect on old-forest area or area with remnant large trees. It was apparent from the area of stand-initiation structures in our historical vegetation coverage, that fire played a major role in regenerating forests, and it is likely that large areas of young and intermediate structure were historically typical for these landscapes. Area with medium and large trees remained relatively unchanged despite the level of timber harvest. In the absence of fires and under the influence of selective harvesting, forest crown cover declined, forest structures became less layered, and large areas developed grass and shrub understories where conifer understories once were more typical. Even area with visible dead trees and snags declined during the sample period.

Among forested ERUs, the Upper Clark Fork was one those most heavily influenced by past timber harvest. It was not surprising that most vulnerability changes were declines. Area and connectivity of area vulnerable to Douglas-fir beetle disturbance declined owing to reduced crown cover of large and medium Douglas-fir across all forest structural classes. Area vulnerable to western pine beetle (type 1) disturbance of mature and old ponderosa pine declined as a consequence of reduced area in the ponderosa pine cover type and reduced crown cover of medium and large ponderosa pine across all forest structural classes.

Area vulnerable to western pine beetle (type 2) and mountain pine beetle (type 2) disturbance of immature, high-density ponderosa pine also declined as a result of reduced area in the ponderosa pine cover type and reduced area of stem-exclusion, understory reinitiation, and young multistory structures with ponderosa pine in pure or mixed compositions. In contrast, area and connectivity of area vulnerable to fir engraver disturbance increased during the sample period. High-vulnerability area increased primarily as a result of increased area in the subalpine fir-Engelmann spruce cover type in all forest structural classes except stand initiation. Vulnerability to dwarf mistletoe disturbances of Douglas-fir, ponderosa pine, and western larch declined during the sample period. The observed decline was the result of significantly reduced patch area and contiguity with medium and large hosts in multilayered structures.

In the historical vegetation condition, more than one-half (53 percent) of all forest cover in the Upper Klamath ERU was ponderosa pine and 23 percent of all forest structure was old forest; 38 percent of all forest structures had at least 10 percent or more crown cover of large trees. In the existing condition, 49 percent of all forest cover is ponderosa pine and 21 percent is old forest; 36 percent of all forest structures have at least 10 percent or more crown cover of large trees, but crown cover of medium and large trees has been substantially reduced. Selection cutting reduced the crown cover of medium and large trees for 31 percent of the forest area. Much like the Upper Clark Fork, in the absence of fires and under the influence of heavy selective harvesting, forest crown cover declined, forest structures became less layered, and large areas developed grass and shrub understories where conifer understories once were more typical. Forest area declined by an average of 3 percent; likewise, area with visible dead trees and snags declined during the sample period. Among forested ERUs, the Upper Klamath was probably the second most heavily influenced by past timber harvest, and as with the Upper Clark Fork, most vulnerability changes were declines.

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Introduction

A biological system, whether individual or ecological, can be considered healthy when its inherent potential is realized, its condition is stable, its capacity for self repair when perturbed is preserved, and minimal external support [from] management is needed....Stability is not the stability implied in the Clementsian view of the community; rather it is compatible with the widespread recognition that biological systems are metastable (*sensu* Botkin 1990).

Our ability to change the world [now] outpaces the ability of biological systems to respond to those changes. Even our minds and our language evolve too slowly to deal with the rate of environmental degradation....Our success as a world society depends on an environmental revolution—on our ability, that is, to change our vocabulary and our perceptions so that we can indeed protect ecological integrity.

No clear standard has been developed to measure biological condition, however, or to define the nature and extent of degradation. The lack of a standard has, by default, resulted in society's ignoring the status of [human] life support systems. No single innovation can reverse that trend. Recognizing the problem as a serious social issue fosters dialogue to define our goals—to define the level of ecological health we can accept as a society. Hence we must develop a rational approach to the definition of ecological health, methods to measure that health, and mechanisms to incorporate protection of ecological health into society's decision-making processes.

James R. Karr (1992)

Forest and range ecosystems of the interior West are exceedingly rich and diverse owing to great variety in climate, geology, landforms, hydrology, flora, fauna, and ecological processes (Bailey 1995, Franklin and Dyrness 1973, Hann and others 1997, Jensen and others 1997, Lee and others 1997, Marcot and others 1997). Recurring disturbances, such as those caused by fires, insects, pathogens, and wind, are essential to maintaining this diversity (Agee 1990, 1993, 1994; Arno 1976, 1980; Edmonds and Sollins 1974; Gara and others 1985; Hagle and others 1994, 1995; Hall 1976; Harvey and others 1992, 1995; Hessburg and others 1994; Martin 1988; Turner 1987, 1989; Wickman 1992). Terrestrial plant communities range from dry, short grass prairies and sagebrush shrublands, to cool and moist western hemlock and western redcedar forests, and high-elevation whitebark pine and subalpine larch forests, krummholz, and heath.[1] Alpine tundras, rock barrens, and glaciers comprise many of the highest elevations.

Landscape patterns and ecological characteristics of these various communities are closely related to their fire, insect, and pathogen ecology. Even though broad landscape patterns of life forms and physiognomic types arise from broad differences in topography and physiography, lithology, geomorphic processes, climate regime, and large-scale

[1] Scientific names of all species are given in table 8.

disturbances, fine and medium grain[2] patterns within the general framework of coarse patterning are the result of environmental gradients, patch-scale and gap disturbance, stand development, and succession processes.

Native fire regimes range from frequent, nonlethal surface fires typical in dry forests of the ponderosa pine and Douglas-fir series,[3] to moderately infrequent, mixed-severity fires characteristic of mesic and moist forests of the grand fir, western hemlock, and western redcedar series, and infrequent, lethal, stand-replacing fires typical in cold subalpine forests.

Native insect and pathogen disturbance regimes also are variable in their frequency, severity, duration, and spatial extent. Pandemic bark beetle and defoliator outbreaks, for example, occur relatively infrequently in any given geographic area (once or twice a century at most), and such outbreaks often are synchronous with climatic extremes and cycles of geographically dominant vegetation structure or composition resulting from other major pattern-forming agents or events. But bark beetle, defoliator, or pathogen disturbance associated with local and endemic populations is ongoing, blending seamlessly with succession and stand-development processes; for example, dwarf mistletoes and root pathogens bring about the mortality of individual large trees over a span of several decades to several centuries, but their effects on composition and structure of landscapes can be quite spectacular because of their wide distribution, longevity, and degree of host specialization. For the most part, it is appropriate to think of native forest pathogens and insects as agents of succession (*sensu* Byler and others 1996, Hagle and Williams 1995, Hagle and others 1995), selectively killing or reducing the growth and vigor of a particular tree species or size class, and thereby bringing about discernible transitions in composition and structure at patch and landscape scales.

Oliver and Larson (1990) present an ordered progression of stand-development phases resulting from stand dynamics and disturbance processes, but in the interior West, insect, pathogen, and fire disturbances bring about a nonsequential progression of transitions (O'Hara and others 1996). Insect, pathogen, and fire disturbances are, in fact, so common and varied in their effects on vegetation structure and composition that both seral status and structural development may be advanced or retarded by individual disturbances or complex interactions among disturbances (see also Keane and others 1996).

Declining health of forest ecosystems in the interior West has been the subject of much study, concern, and controversy in recent years (for example, see Agee 1994, Byler and others 1994, Byler and Zimmer-Grove 1990, Everett and others 1994, Gast and others 1991, Harvey and others 1995, Hessburg and others 1994, Huff and others 1995, Lehmkuhl and others 1994, Monnig and Byler 1992, O'Laughlin and others 1993, Wickman 1992). Land-use practices of the last 100 years have altered disturbance regimes, spatial and temporal patterns of vegetation, and reduced ecosystem resilience in the face of ongoing disturbance. Concern over "declining forest health" centers around the human perception that past forest management activities have had a deleterious effect on forest ecosystem structure and functioning. The perception is founded on the widely held social value that forest (and rangeland) ecosystems ought to appear natural and be allowed to function naturally. In that context, significant departure from native conditions in the appearance of forests, in attributes of disturbance regimes (such as disturbance frequency, duration,

[2] The grain of a given landscape is a function of the average size and size range of patches comprising that landscape; for example, a landscape with a coarse grain is comprised of relatively large patches ranging in size from hundreds to perhaps thousands of hectares. A landscape of fine grain is comprised of many small patches ranging from a fraction of a hectare to several hectares. The grain of any given landscape depends on the scale at which agents of pattern formation operate locally and the scale of observation.

[3] A *series* is a conceptual grouping of related plant associations having the same predicted dominant climax species; the series takes the name of the dominant species. A *plant association* is a potential vegetation type in a hierarchical classification scheme directly beneath the series level; the plant association takes the name of a predicted climax community type. A *community type* is a conceptual synthesis of all plant communities having similar structure and floristic composition with no successional status implied; it is simply an assemblage of plants that live together, interact, and compete among themselves (Daubenmire and Daubenmire 1968, Driscoll and others 1984).

distribution, intensity, and extent), and in other vital ecosystem processes (such as succession, species migration, speciation, extinction) is indicative of unnatural or deviant functioning and uncertain outcomes. Hence, by virtue of the perceived deviant functioning and unease with expanding uncertainty, a negative connotation is applied to changing ecosystems in the notion of "declining ecosystem health."

Fire suppression, timber harvest, and livestock grazing have contributed most to increased forest ecosystem vulnerability to insect, pathogen, and wildfire disturbance (Agee 1994, Everett and others 1994, Gast and others 1991, Hann and others 1997, Hessburg and others 1994, Johnson and others 1994, Lehmkuhl and others 1994, Martin and others 1976). These conditions are not pervasive, however, and some forests remain in relatively healthy[4] and productive condition.

Many studies focusing at the stand level have characterized fuel loading (Fischer 1981; Maxwell and Ward 1976, 1980) and fire behavior characteristics (Anderson 1982, Brown and See 1981, Fahnestock 1976, Ward and Sandberg 1981) for a broad range of forest structural conditions occurring across an equally broad range of potential vegetation types. Likewise, numerous hazard rating systems have been devised to assess the susceptibility of stands of varying structure, composition, age, vigor, and density to bark beetle disturbance (for example, see Amman and others 1977; Amman and Anhold 1989; Berryman 1978, 1982; Cole 1978; Cole and Cahill 1976; Crookston and others 1977; Mahoney 1978; McGregor 1978; Miller and Keen 1960; Mitchell 1987; Mitchell and others 1983a, 1983b; Roe and Amman 1970; Safranyik and others 1974, 1975; Schenk and others 1980; Shore and others 1989; Stuart 1984; Waring and Pitman 1980) or defoliator infestation (Carlson and others 1985; Heller and Kessler 1985; Stoszek and Mika 1984, 1985; Wulf and Carlson 1985). Stand structural and compositional conditions most conducive to damage by dwarf mistletoes and root pathogens have been characterized, modeled, and articulated as well (Dixon and Hawksworth 1979; Edminster 1978; Edminster and others 1991; Geils and Mathiasen 1990; Hadfield and others 1986; Hawksworth and Johnson 1989; Hawksworth and others 1995; Knutson and Tinnin 1980; Myers and others 1971, 1976; Parmeter 1978; Robinson and Sutherland 1995; Stage and others 1990; Strand and Roth 1976). But little is known of the effects of cumulative stand-level shifts in forest composition and structure over long time spans on landscape composition, structure, and patterns. Even less is known about the effects of shifting landscape patterns on fire, insect, and pathogen disturbance processes or their interactions.

This paper is the first part of a two-part study conducted under the aegis of the Interior Columbia Basin Ecosystem Management Project (ICBEMP). Here, we report on a midscale scientific assessment of vegetation change in terrestrial landscapes of the interior West and associated change in landscape vulnerability to potential insect and pathogen disturbances. Part II (Ottmar and others, in prep.) will evaluate change in ground fuel conditions, potential fire behavior, and related smoke production associated with reported vegetation change. Our assessment area included the interior Columbia River basin east of the crest of the Cascade Range in the Western United States and portions of the Klamath and Great Basins in Oregon (collectively, the basin).

Our study had five objectives:

1. To characterize current structure and composition of a representative sample of forest and range landscapes distributed throughout the basin.

2. To compare existing vegetation conditions (1981-93) to the oldest historical vegetation conditions (1932-66) we could reconstruct at a comparable scale. This was done with the hope of better understanding directions, rates, and magnitudes of vegetation change occurring

[4] In this paper, we say that a forest is healthy when its inherent potential is realized, its condition is metastable, and its capacity for self-repair when perturbed is preserved. Inherent potential is the product of biophysical environment, climate, associated disturbance and other ecological processes. A metastable condition involves continuous yet bounded change; change is bounded in its nature and magnitude due to dominant features of environment, climate, and disturbance regimes.

during the first century of active resource management and exploitation. Our sampling period, although less than 100 years, corresponded well with the period of most intensive timber harvest, road construction, and fire suppression; a period of intermediate or declining intensity in range management; and a period of comparable climate regime.

3. To link historical and current vegetation patterns with landscape vulnerability to potential insect and pathogen disturbances to better understand patterns and disturbance vulnerability relations and more directly characterize some effects of historical management practices.

4. To link historical and current landscape vegetation characteristics throughout the basin with fuel conditions, potential fire behavior, and related smoke production. Our rationale was twofold: these links would enable us to better understand causal connections among historical management activities, such as selective harvesting, fire exclusion, and domestic livestock grazing, and current conditions for potential fire behavior and smoke production; and they would assist us in evaluating current air quality and human health tradeoffs associated with wild and prescribed fires.

5. To synthesize and summarize our findings so that our information might provide regional and subregional contexts for Federal and other management agencies to formulate ecologically sound management strategies for terrestrial ecosystems.

We speculate on possible relations between historical land use and our results, considerations for future management, and research and validation questions that can be answered with further analysis of these and supporting data.

Methods

Study Area

In this study, we sampled environments and vegetation conditions representative of each of the major forest and range provinces of the basin. We characterized recent historical and current vegetation composition and structure of each of these sampled environments and compared landscape patterns, vegetation structure and composition, and landscape vulnerability to major insect and pathogen disturbances of historical and current vegetation coverages. The study area included all of Washington and Oregon east of the crest of the Cascade Range, nearly all of Idaho, and portions of northwestern Montana, western Wyoming, northern California, northern Utah, and northern Nevada (fig. 1). The following Bailey provinces (from Bailey 1989, 1994a, 1994b, 1995) were included in the study area: Northern Rocky Mountain Forest—M333, Cascade—M242, Great Plains-Palouse Dry Steppe—331, Middle Rocky Mountain—M332, Intermountain Semidesert—342, Intermountain Semidesert and Desert—341, Sierran—M261, and Southern Rocky Mountain—M331.

Overview of Biophysical Environments

In this section (adapted from Bailey 1995), we briefly describe broad, province-scale differences in environments of the basin to provide a general overview of biological and physical environment and climatic conditions of the study area. At the end of this "Methods" section, we introduce ecological reporting units (ERUs), province-scale land units used as statistical pooling strata for reporting results of change analysis. Ecological reporting units were developed as land units useful for generalizing results of all broad-scale and midscale basinwide ecological, social, and economic assessments. Because ERUs do not represent purely biophysical environments, we briefly review differences in province-scale ecological land units of the basin. Refer to Jensen and others (1997) for an indepth, multiscale discussion of basin biophysical and hydrologic environments.

Northern Rocky Mountain Forest Province—Landforms of the Northern Rocky Mountain Forest Province (fig. 1) consist primarily of high, glaciated mountains separated by broad, flat valleys. Winters can be severe with a heavy snow pack. Dry growing seasons result from strongly influential westerly air masses; climatic regimes are maritime where Pacific Coast influence dominates and continental elsewhere. Precipitation averages 51 to 102 cm annually and is concentrated in fall, winter, and spring. Forests are mixed coniferous and deciduous, with Douglas-fir and cedar-hemlock often dominating.

Elevation belts are clearly indicated by lifeform changes. Alpine[5] environments are barren and tundralike;[6] subalpine[7] belts are dominated by Engelmann spruce, subalpine fir, or mountain hemlock forests as in the Bitterroot Mountain

[5] Alpine environments occur above upper treeline and below the snow line in mountainous regions. With the exception of subalpine (often called alpine) larch, conifers are unable to persist in these environments in an upright growth form.

[6] Barren treeless environments are found north of the Arctic Circle and above the upper tree line of high mountains (alpine tundra). Tundra environments are characterized by very low winter temperatures and short cool summers; soils display a permafrost layer beneath the uppermost layers affected by summer melt. Tundra vegetation is dominated by lichens, mosses, sedges, low shrubs, and subshrubs.

[7] Subalpine environments occur near the upper treeline. For much of the year, these environments are snow covered, cold, and often harsh. For most coniferous species, the subalpine zone defines the upper elevation range of conifers.

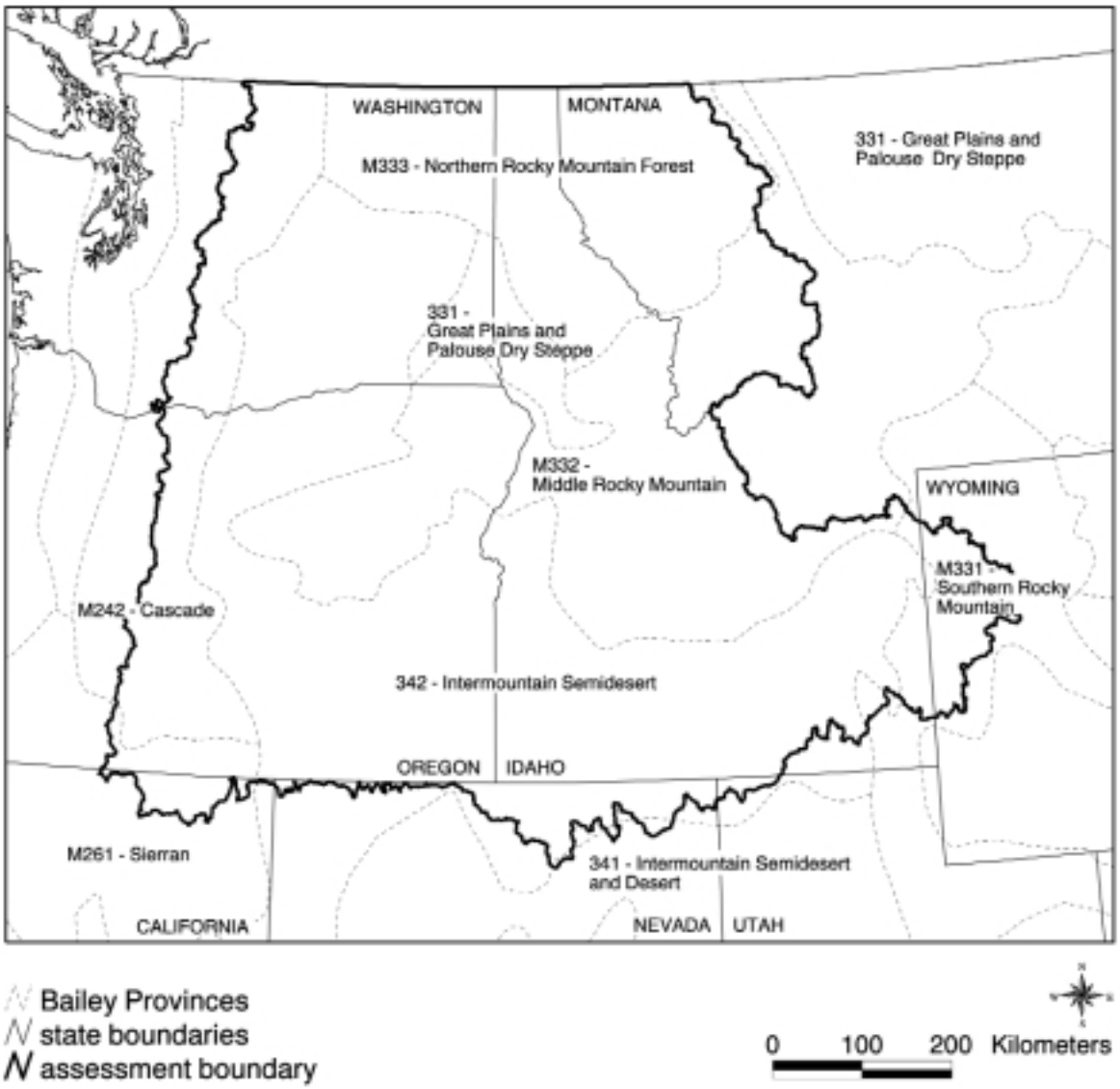

Figure 1—Interior Columbia River basin assessment area with Bailey province boundaries.

Range. Western hemlock and western redcedar forests characterize montane settings in association with Douglas-fir, western white pine, western larch, grand fir, and to a lesser extent ponderosa pine. Lower montane[8] and colline[9] environments are dominated by grasses and sagebrush.

Soils are cool and moist Inceptisols and are often shallow and stony, but unlike elsewhere in the Rocky Mountains, these factors play a minor role in the distributions of forests. Foothill soils tend to be quite productive as a result of rich loess[10] and ash deposits.

Cascade Province—This province is bisected by the study area boundary (fig. 1). We adapted the description so that it pertains to the portion of the province within the basin study area. Dominant landforms of the Cascade Province are the result of widespread volcanic activity. Rugged mountains of the northern Cascades of Washington also have been repeatedly glaciated. Terrain in the north is steep and highly dissected with relatively narrow valley bottoms except where glaciated. Maritime climatic regimes dominate throughout because of the close proximity and influence of Pacific Coast air masses. Precipitation is heavy at the crest and declines rapidly to the east due to rain shadow effects. Annual precipitation at the crest is 380 cm; eastern foothills receive as little as 51 cm precipitation annually. Fog partially compensates for droughty summer seasons. Most precipitation occurs as snow.

[8] Montane environments are relatively cool, moist upland habitats occurring above the lower treeline, where coniferous vegetation often dominates. Lower montane environments are among the driest forested settings. They occur immediately above the lower tree line. Upper montane environments support coniferous vegetation favoring cool to cold and moist to wet growing conditions.

[9] Colline environments occur immediately below the lower treeline.

[10] Loess, in this usage, refers to soil accumulations derived of fine, unconsolidated, wind-blown volcanic ash and glacial till. In other areas, loess accumulations are the result of aeolian (wind blown) deposits and may be alluvial (silty deposits initially transported by water), colluvial (deposits initially transported by gravity), or lacustrine (lake bottom) in origin.

Vegetation patterns in the northern and southern extremes of the province are distinctly different. At the northern end, alpine environments are glaciated or barren close to the Cascade crest and are tundralike to the east. Subalpine belts are dominated by mountain hemlock forests and tree-islands intermixed with heath shrublands at the crest. Subalpine fir and Engelmann spruce intermixed with subalpine herblands dominate to the east. Whitebark pine and subalpine larch occur sporadically throughout. Pacific silver fir, western hemlock, Douglas-fir, and noble fir characterize montane forests at the crest; to the east, grand fir, Douglas-fir, western larch, and ponderosa pine dominate. Ponderosa pine and sagebrush steppe[11] characterize the lower montane and colline elevation belts found mainly to the east.

At the southern end of the province, alpine belts are tundralike and barren. Mountain hemlock and lodgepole pine dominate subalpine forests intermixed with barren herblands. Shasta red fir provides the transition to montane forest types dominated by grand fir or white fir, Douglas-fir, and ponderosa pine. Lodgepole pine forms extensive forests in this belt on flat ground. Ponderosa pine, western juniper, and sagebrush dominate lower montane and colline settings.

Andisols are extensive and often overlay volcanic ash. Moist Inceptisols are widely distributed west of the Cascade crest, but soils east of the crest are dry and erosive as a result of deposition of unconsolidated volcanic ash.

Great Plains-Palouse Dry Steppe Province—Landforms of the Palouse dry steppe region (fig. 1) consist of rolling plains and loess-covered basalt tablelands ranging in elevation from 370 to 1800 m. Plains are flat or rolling and frequently dissected by valleys and canyons. The Palouse short grass prairies lie in the rainshadow of the Cascade Range in Washington, where summers are hot and dry. Throughout the Great Plains, winters are cold and dry; but on the Palouse steppe, precipitation reaches its maximum in the winter. Precipitation ranges from 26 cm in

[11] Steppe refers to semiarid, treeless environments where shrub or herbaceous species comprise the dominant vegetative cover.

the northern portion of the province to more than 64 cm in the south, with maximum rainfall occurring during summer. Evaporation usually exceeds precipitation; when precipitation occurs, it often comes as hail storms and blizzards.

At the time of this assessment, much of the native herbland vegetation of the Palouse region had already been converted to dryland agriculture. What remains, except for remnant shrublands and relict[12] juniper woodlands, are small isolated islands comprised of native short grasses, such as bluebunch wheatgrass, Idaho fescue, and bluegrasses, and often other nonnative grasses and forbs. Soils are derived of rich loess accumulations deposited during periods of glacial recession. Mollisols are common, but humus depth is typically minimal because vegetation is sparse.

Middle Rocky Mountain Province—The Middle Rocky Mountains Province is comprised of the Blue Mountains, Salmon River Mountains, and the basins and ranges of southwestern Montana (fig. 1). Central Idaho and the Salmon River Mountains developed from granitic intrusions that collectively make up what is known as the Idaho Batholith. Terrain is deeply dissected in the batholith with much evidence of weathered granitic substrates. In southwestern Montana, basin and range landforms are mountains with broad alluvial plains at their bases. Most of the highest peaks throughout the province have been influenced by repeated glaciation. The Blue Mountains in the western portion of the province are comprised of uplifted basalts originating from repeated overland flows associated with the Columbia River Basalt Group.

Climate within the province is strongly influenced by maritime air flows up the Columbia mainstem from the Pacific Ocean, but continental influences also are apparent in the southwestern portion of the province, especially in the John Day and Malheur basins. Precipitation in montane forests occurs mostly as snow, and interior valleys tend to be dry and semiarid. Valleys receive less than 51 cm of precipitation annually, but mountainous regions may get up to 77 cm.

[12] Relict, in this usage, refers to a persistent remnant of a formerly widespread western juniper woodland existing in isolated areas.

Clear zones of vegetation by elevation belt are evident. Alpine settings are tundra. Whitebark pine, subalpine fir, and Engelmann spruce dominate subalpine belts. Lower montane forests are dominated by ponderosa pine, and midmontane environments are comprised chiefly of Douglas-fir and grand fir in the more moderate aspects and elevation settings. Lodgepole pine and grasses dominate the basins and ranges in the eastern and southeastern portions of the province. Colline semidesert environments are dominated by sagebrush and short grasses.

Soils of the alluvial fans and interior valleys are Mollisols, which support sagebrushes and grasses. Above 610 m, forest soils are Alfisols except where glaciated or with steep slopes; Inceptisols predominate in the latter locations.

Intermountain Semidesert Province—The Intermountain Semidesert Province (fig. 1), which includes the Columbia River and Snake River plains in eastern Oregon and Washington, southern Idaho, and the Wyoming basin, is the largest province of the basin study area and spans more than 412 000 km^2. Landforms consist of flat to rolling plains and tablelands. Above 762 m, plateaus are surrounded by folded and faulted lava ridges, which make up most of the lava fields of the region. In the southern portion of the province, intermountain basins and isolated mountain ranges meet strongly dissected plateaus.

Climate of the high plateaus is cool and semiarid. Average annual precipitation ranges from a low of 25 cm in the rangelands just east of the Cascade Range, to 51 cm farther east; accumulations are somewhat evenly distributed throughout fall, winter, and spring. Winters are long and cold, and summers are hot and dry. Because of the higher elevation of the Wyoming basin, its climate is cooler than that of the rest of the province, and average precipitation is typically lower, ranging from 13 to 36 cm annually. Summers there are short, hot, and dry, and winters can be quite severe.

Steppe vegetation is dominated by sagebrushes, shadscale, and short grasses. In central Oregon, a large area of western juniper-dominated woodland is apparent where annual precipitation exceeds 25 to 30 cm. Colline valley bottoms are lined with

willows and sedges, and those of the intermountain valleys support greasewood and other alkali-tolerant shrubs and herbs. Moist alkali flats also commonly support greasewood cover types. In eastern Washington, areas that once were dominated by bunchgrass herblands now support extensive dryland wheat farms.

Rich alluvial deposits are widespread throughout this province in broad flood plains and at the bases of the Cascade and central Idaho mountains. Dry lake beds are numerous as are dune and loess deposits. Aridisols dominate throughout the province in basin and lowland areas. Mollisols are typical in the higher elevations. Soils of the Wyoming basin, also Aridisols, are alkaline enriched with lime and gypsum, and hardpans[13] often form naturally or with cultivation. Entisols make up much of the Bighorn basin soils.

Intermountain Semidesert and Desert Province—This province enters the basin assessment area at its southern edge in Nevada (fig. 1). Great Basin and northern Colorado Plateau physiographies comprise most of the area. Really a misnomer, the Great Basin consists of many smaller basins with no outlet to the sea. Landforms are varied with mountains rising sharply from semiarid shrub-covered plains. Mountains are well vegetated, but conifer forests are few and limited to the uppermost elevations of high mountains. Summers are hot, and winters are moderate. Annual precipitation averages 13 to 49 cm, much of which accumulates as snow. Almost no rain falls during summer, except occasionally in the mountains. Spring seasons are typically long because mild temperatures come early to the Great Basin, especially in the lower elevations.

Alkaline soil conditions are widespread, and most vegetation is semitolerant of alkali. Lower elevations are dominated with sagebrush often associated with bitterbrush, shadscale, saltbush, rabbitbrush, hopsage, and horsebrush. In the most alkali areas, greasewood and saltgrass cover types dominate. In areas currently sagebrush dominated, steppe grasses such as those of the Palouse Prairie once were more abundant. Current widespread distribution of sagebrushes may be the result of repeated historical overgrazing combined with fire suppression. At higher elevations above a conspicuous shrubland belt, pinyon pine and juniper woodlands dominate. Above the woodlands, ponderosa pine dominates exposed slopes and Douglas-fir the higher, more sheltered settings. Subalpine environments, when occurring, are comprised of subalpine fir and Engelmann spruce. Exact composition of forested settings differs considerably from mountain range to mountain range, presumably the result of differing migration rates. As in the preceding province, soils of basin and lowland areas are Aridisols, and Entisols line some flood plains in narrow bands. Salt flats[14] and playas[15] are typical in the lower elevations of basins with interior drainage.

Sierran Province—The Sierran Province is comprised of the southern extremity of the Cascade Range in Oregon, the northern Coast Range in southwest Oregon, the Klamath Mountains of southern Oregon and northern California, and the Sierra Nevada of east-central California. Of this large area, only the Klamath Mountains and southern Cascades are included in the basin assessment area (fig. 1). Landforms of the province consist of steep to precipitous mountains separated by valleys with long and relatively steep elevation gradients. The Sierra Nevada drop off abruptly to the Great Basin region to the east, and more gradually to the west. Within the basin assessment area, only alpine environments of the Klamath Mountains are glaciated, and subalpine and alpine environments are rugged.

Air masses from the Pacific Coast influence the climate of most of the region. Within the study area, average annual precipitation ranges from 25 to 178 cm with rain and snow occurring in roughly equal proportion. Dense, mixed coniferous forests occupy the montane zone (900 to 2100 m) where the greatest total precipitation

[13] A hardpan is a compacted layer in the B-horizon of a soil typically rich in deposited salts, and restricting drainage and root penetration. The B-horizon is an upper subsoil layer with an accumulation of clay, humus, iron, and various oxides as a result of leaching and translocation from upper layers.

[14] Salt flats are salt-covered, flat-floored, ancient lake beds remaining after an inland lake has evaporated.

[15] Playa is the flat bottom of an undrained desert basin that at times becomes a shallow lake.

occurs. Subalpine settings receive as much as 100 to 125 cm of precipitation, with most occurring as snow.

Elevation zones are distinctly marked by lifeform and vegetation changes. Montane forests within the assessment area are dominated by ponderosa at lower elevations, and Douglas-fir, sugar pine, incense-cedar, Shasta red fir, and white fir in middle and upper elevations. Subalpine forests are composed of Shasta red fir, mountain hemlock, lodgepole pine, western white pine, and an occasional whitebark pine. Below lower treeline, ponderosa pine gives way to juniper woodlands. On mountain slopes where the coastal influence is greatest, soils are Ultisols, whereas dry Alfisols are more typical in lower montane and colline environments. Alluvial and fluvial soils are typically Entisols.

Southern Rocky Mountain Province—In the Southern Rocky Mountain province, only the Snake River headlands in southeastern Idaho and western Wyoming reside within the basin assessment area (fig. 1). Landforms include glaciated high mountains with peaks of 4300 m or more, intermontane parks (herblands and shrublands) or depressions at intermediate elevations (< 1800 m), and semiarid valleys at lower elevations. Climate is dry, resulting primarily from continental air masses. Primary factors of influence to climate are prevailing westerly winds and the north-south orientation of major ranges. The west slope of the Rocky Mountains within this province area receives considerably more moisture than the eastern slope. Average annual precipitation ranges from 25 cm at the lowest elevations to as much as 100 cm in the high mountains where most precipitation occurs as snow.

Distinct vegetation zones are the direct result of elevation and latitude gradients, prevailing winds, and the degree of slope exposure. North aspects and narrow valleys support vegetation associated with the coldest environments for growth and survival. Alpine settings are tundra or barren; subalpine environments are dominated by subalpine fir and Engelmann spruce. Lodgepole pine and aspen are important early seral components of montane and subalpine environments. Montane environments are dominated by Douglas-fir and ponderosa pine; ponderosa pine is especially prominent in the lowest and driest montane settings, and Douglas-fir is restricted to more mesic[16] and sheltered environments. Foothill colline environments within the assessment area are comprised of mixed conifer woodlands, sagebrush, scrub oak, maple, mountain-mahogany, or bitterbrush shrublands, and herblands. Aridisols are characteristic of foothills environments, Mollisols and Alfisols are characteristic of lower and mid-montane settings, and steep glaciated slopes typically have Inceptisols.

Sampling Design

Software tools—In this section, we describe the computing hardware and software we used and its application in this project to provide an analytical context for the subsequent descriptions of methods. We used various commercially available computer hardware and software products to complete this assessment, including geographical information systems (GIS); packages for statistical, spatial, and ecological data analysis; relational databases and spreadsheets; and programming language compilers for custom, inhouse software. These programs were used on several hardware-operating system platforms, including Sun® workstations and X-terminals with Solaris® (Sun's Unix operating system) and personal computers with OS/2® and DOS/Windows® operating systems.[17]

This assessment was a map-based characterization of landscape patterns and ecological processes across space and time. We used two GISs to manipulate and analyze digital maps: ARC/INFO (ESRI 1995) was the principal GIS used for most analyses, and GRASS (USACERL 1992) was used in analyses leading to sample stratification. ARC/INFO was used with a wide variety of maps to manipulate, combine, and query coverages to derive data sets for further analysis with other

[16] Mesic pertains to environmental conditions of moderate moisture or water supply; applies to organisms that occupy habitats displaying intermediate levels of soil moisture or water availability.

[17] The use of trade or firm names in this publication is for reader information and does not imply an endorsement by the U.S. Department of Agriculture of any product or service.

software. We used ARC/INFO's macroprogramming language (AML) to develop and run inhouse spatially explicit models, such as our insect and pathogen vulnerability characterizations (Hessburg and others, in press), and potential fire behavior models (Ottmar and others, in prep.).

Spatial and statistical analyses were done to characterize change in patterns and to quantify statistical and ecological significance of those changes. FRAGSTATS (McGarigal and Marks 1995) was used to compute a variety of class and landscape pattern metrics directly from ARC/INFO data tables; FRAGSTATS is distributed with a source code for Unix operating environments. We modified the FRAGSTATS source code by incorporating additional metrics and correcting computational errors of several algorithms. S-PLUS (MathSoft Inc. 1993) is a statistical package that reads ARC/INFO data files directly. We used it to summarize ARC/INFO and FRAGSTATS outputs. Summaries were displayed in tabular and graphic formats.

A spatially explicit context was not required for some analyses. Data were generated by ARC/INFO and exported into a Paradox® relational database or Excel® spreadsheet. Ad hoc queries were used to generate summaries and reports. Paradox also was used to derive or model other attributes, such as potential vegetation type described later in this section (see also Smith and others, in prep). An ecological data analysis package, EcoAid,[18] which reads Paradox data files directly, was used to conduct some ordination and cluster analyses. Other inhouse programs that read from or wrote to Paradox files also were written for computations not available in conventional software packages. These programs are available through the first and second authors.

Land and hydrologic unit sampling framework—To provide insight into management-induced cause-and-effect relations between terrestrial and aquatic ecosystems, it is preferable that ecological characterizations classify environments as terrestrial (both biological and physical dimensions) and hydrologic, at scales appropriate to observing the patterns, processes, and interactions of interest. If, for example, an analysis is conducted to evaluate effects of roads on the distribution of native trout life histories in an area, land areas ought to be hydrologic domains sufficiently large to represent a nearly full complement of trout life histories. If that were not the case, it would be difficult to separate effects of stream network size from the effects of roads on bull trout life histories. For reasons such as these, we chose large sample units, unique in their hydrology, climate, geology, vegetation, and landform. The ECOMAP land unit hierarchy (ECOMAP 1993) provided a framework for ecological land units used in this assessment; the U.S. Geological Survey (USGS) hydrologic unit hierarchy (Seaber and others 1987) provided an initial framework for hydrologic units. Both were used to stratify watersheds of the basin for sampling and characterization.

The USGS hydrologic unit hierarchy supplied a nested, four-level classification of watersheds of similar size and scale for the entire United States. The fourth level in that hierarchy (subbasin or 4th Hydrological Unit Code [HUC]) was used to initially stratify watersheds of the interior Columbia River basin assessment area for sampling. In addition, results from the Eastside Forest Ecosystem Health Assessment (Everett and others 1994, Lehmkuhl and others 1994) indicate that smaller hydrologic units of 4000 to 8000 or more ha were suitable for characterizing, on a sampling basis, patterns and changes in structural attributes (both composition and configuration) of vegetation within 4th code HUCs. Complete hydrologic unit coverages of this scale for the entire interior Columbia River basin were lacking in the existing USGS hierarchy. Consequently, two additional nested levels (5th code HUCs or watersheds, and 6th code HUCs or subwatersheds) were developed within the established fourth level of the hierarchy for this assessment (fig. 2). Refer to Jensen and others (1997), for a description of watershed and subwatershed delineation methods.

Subbasin stratification and subwatershed selection—Subbasins were selected from a formal stratification of all subbasins in the basin by

[18] EcoAid is an inhouse software package for analyzing ecological data sets. Copies are available on request from the second author.

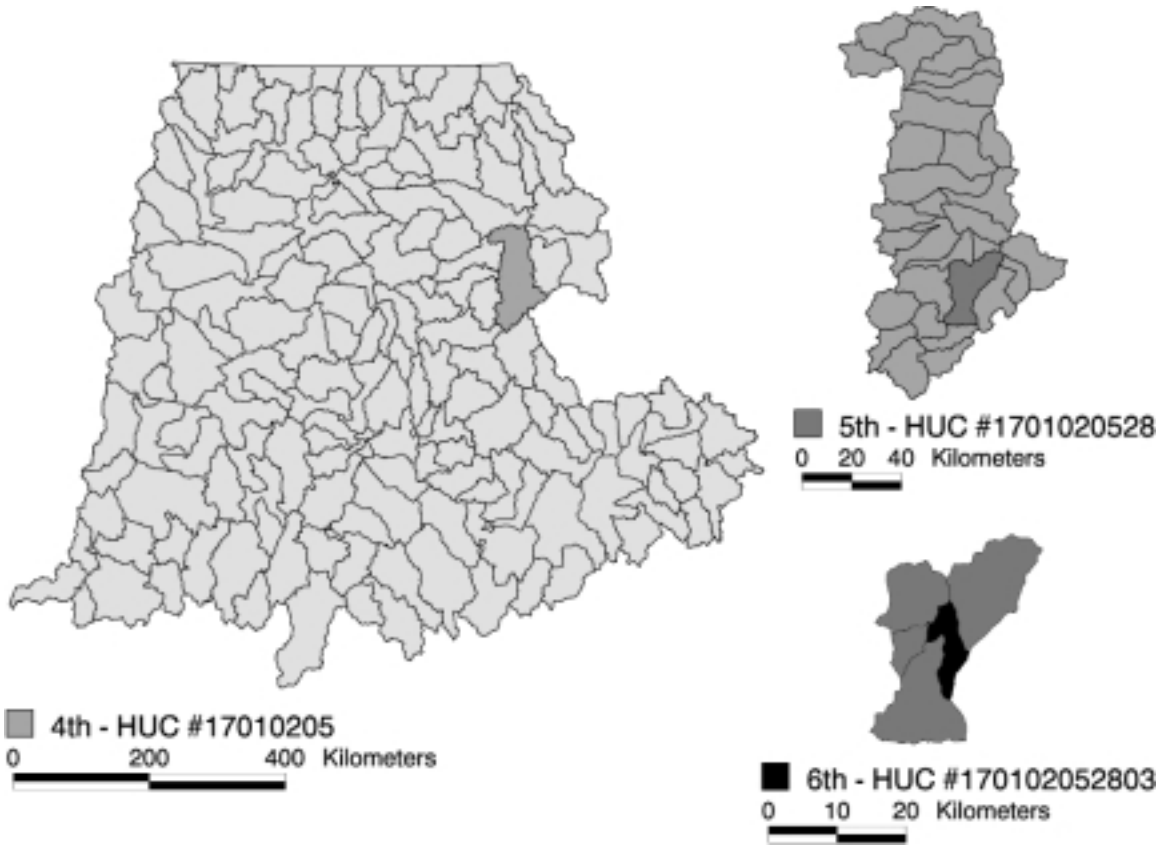

Figure 2—Hierarchical organization of subwatersheds (6th code HUCs), watersheds (5th code HUCs), and subbasins (4th code HUCs) in the interior Columbia River basin and portions of the Klamath and Great Basins.

their Bailey province membership and similarity of area in 304.8-m elevation zones. Subbasin areas in each elevation zone were derived in a GIS by using a 90-m digital elevation model (DEM) resampled to 1-km cell size. Similarity analyses employed the percent similarity (PS) algorithm (Pielou 1984) shown below:

$$PS = 200 \frac{\Sigma \min(x_i, y_i)}{\Sigma x_i + \Sigma y_i},$$

where
x_i= the measure of attribute i in subbasin x, and
y_i= the measure of attribute i in subbasin y.

The generated pixel data were treated like any ecological data set consisting of sample units (subbasins) with species abundances (pixel counts within each province-elevation class). The intent was to classify groups of similar subbasins. A smaller set of subbasins was then randomly drawn from within each group, from which subwatersheds were randomly selected. Each group contained similar subbasins where the attributes of similarity were the province-elevation classes. Because provinces were, by definition, relatively homogeneous ecological land units at that scale (ECOMAP 1993), this was a reasonable method of stratification. A recursive analysis was used; each analysis cycle consisted of several steps:

1. The clustering procedure TWINSPAN (two-way indicator species analysis) was used to divide the data in four to eight groups (Hill 1979).
2. Two similarity index tables were developed from the PS algorithm (Pielou 1984). The first table was a subbasin-by-subbasin comparison. The PS uses abundance data to weight the importance of each attribute; for example, two subbasins with similar attributes that have similar abundance values will have higher similarity values than two subbasins also having similar attributes but divergent abundance values. The second table was a cluster-by-cluster comparison using TWINSPAN output. These values represented averages of all the within- or among-group similarity values from the first table. Assessment of cluster homogeneity for presence or absence of attributes was possible with this table.
3. We used the similarity analysis described above to further refine membership of each cluster. We repeated the process for each cluster defined above, applying steps 1 and 2 for each cluster, and stopped when further division produced clusters too small to be useful, or when further subdivision was not ecologically meaningful.

Sixteen subbasin strata were the result of stratification (table 1). Strata contained 4 to 18 subbasins, of which 2 to 4 were randomly selected without replacement from each stratum for sampling. We duplicated the sampling intensity used in the Eastside Forest Ecosystem Health Assessment (Everett and others 1994, Lehmkuhl and others 1994) and allocated that intensity across each stratum in proportion to stratum size. Subbasins previously selected for the Eastside Forest Ecosystem Health Assessment were included in the sample as these data were readily available; subwatersheds within these subbasins also were selected randomly. In all, 43 subbasins were sampled. Table 2 lists sampled subbasins by Bailey province, Omernik ecoregion, and state. Figure 3 displays the locations of all sampled subbasins in the basin study area. Figure 4 shows selected subbasins as they were grouped for mapping, and figures 5 to 22 display subwatersheds within subbasin groupings.

Subwatersheds were randomly selected for vegetation mapping until at least 15 percent of the area of each selected subbasin was represented. We researched availability of recent historical aerial photography for each selected subwatershed at the Cartographic Branch of National Archives offices in Washington, DC, and Salt Lake City. For a few subbasins, historical aerial photographic coverages of randomly selected subwatersheds were either unavailable or incomplete. In most cases, subwatersheds lacking adequate coverage were those comprised primarily of private lands or rangelands. As a general rule, if a subwatershed contained in excess of 55 to 60 percent private land, historical photography would be absent or of insufficient coverage to characterize vegetation conditions. Subwatersheds with insufficient photo coverage were randomly replaced as they were encountered in the draw with others having sufficient coverage. If historical photography was available for a random selection of subwatersheds comprising less than 15 percent of the subbasin area, a new subbasin was randomly selected from within the same stratum.

Availability of the most current resource aerial photography was researched at appropriate local offices of the Forest Service, Bureau of Land Management, or state departments of forestry or natural resources. Ultimately, 337 subwatersheds were sampled in 43 subbasins, and historical and current vegetation maps were constructed for each sampled subwatershed from remotely sensed attributes.

One concern with using subwatersheds of differing area in vegetation pattern analyses is the well-known correlation of some landscape pattern attributes with landscape area (O'Neill and others 1988, Turner 1989). Lehmkuhl and Raphael (1993) show that sample estimates of landscape attributes change asymptotically rather than linearly with landscape area. We used sample subwatersheds averaging at least 4000 ha to avoid bias associated with small sampling units. When subwatersheds smaller than 4000 ha were encountered in the sample, they were joined with an adjacent subwatershed to form a larger logical hydrologic unit.

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Table 1—Stratum membership of subbasins sampled in the midscale ecological assessment of the interior Columbia River basin

Stratum	Subbasin name	4th code HUC	Stratum	Subbasin name	4th code HUC
1	Goose Lake	18020001	6	Middle Columbia-Hood	17070105
1	Lost	18010204	6	Naches	17030002
1	Upper Klamath	18010206	6	Similkameen	17020007
1	Upper Klamath Lake	18010203	6	Sprague	18010202
2	Chief Joseph	17020005	6	Upper Columbia-Entiat	17020010
2	Clearwater	17060306	6	Upper Deschutes	17070301
2	Coeur d'Alene Lake	17010303	6	Upper Yakima	17030001
2	Colville	17020003	6	Wenatchee	17020011
2	Franklin D. Roosevelt Lake	17020001	6	Williamson	18010201
2	Hangman	17010306	7	Gros Ventre	17040102
2	Kettle	17020002	7	New Fork	14040102
2	Little Spokane	17010308	7	Snake Headwaters	17040101
2	Lower Kootenai	17010104	7	Upper Green	14040101
2	Lower Spokan	17010307	8	American Falls	17040206
2	Okanogan	17020006	8	Blackfoot	17040207
2	Pend Oreille	17010216	8	Greys-Hobock	17040103
2	Pend Oreille Lake	17010214	8	Idaho Falls	17040201
2	Priest	17010215	8	Lake Walcott	17040209
2	Sanpoil	17020004	8	Lower Henry's	17040203
2	Upper Spokane	17010305	8	Palisades	17040104
3	Banks Lake	17020014	8	Portneuf	17040208
3	Lower Crab	17020015	8	Salt	17040105
3	Lower Snake	17060110	8	Teton	17040204
3	Middle Columbia Lake-Wallula	17070101	8	Willow	17040205
3	Moses Coulee	17020012	9	Alvord Lake	17120009
3	Upper Columbia-Priest Rapids	17020016	9	Beaver-South Fork	17070303
3	Upper Crab	17020013	9	Donner und Blitzen	17120003
4	Palouse	17060108	9	Goose	17040211
4	Lower Snake-Tucannon	17060107	9	Guano	17120008
4	Rock	17060109	9	Harney-Malheur Lakes	17120001
4	Walla Walla	17070102	9	Lake Abert	17120006
5	Lower Crooked	17070305	9	Raft	17040210
5	Lower John Day	17070204	9	Salmon Falls	17040213
5	Trout	17070307	9	Silver	17120004
5	Umatilla	17070103	9	Silvies	17120002
5	Willow	17070104	9	South Fork Owyhee	17050105
6	Klickitat	17070106	9	Summer Lake	17120005
6	Lake Chelan	17020009	9	Thousand-Virgin	16040205
6	Little Deschutes	17070302	9	Warner Lakes	17120007
6	Lower Deschutes	17070306	9	Upper Quinn	16040201
6	Lower Yakima	17030003	10	Bruneau	17050102

Table 1—Stratum membership of subbasins sampled in the midscale ecological assessment of the interior Columbia River basin (continued)

Stratum	Subbasin name	4th code HUC	Stratum	Subbasin name	4th code HUC
6	Methow	17020008	10	Bully	17050118
10	Burnt	17050202	12	South Fork Payette	17050120
10	C.J. Strike Reservoir	17050101	12	South Fork Salmon	17060208
10	Crooked-Rattlesnake	17050109	12	Upper Selway	17060301
10	East Little Owyhee	17050106	13	Big Wood	17040219
10	Jordan	17050108	13	Camas	17040220
10	Lower Boise	17050114	13	Little Wood	17040221
10	Lower Malheur	17050117	13	Lower Middle Fork Salmon	17060206
10	Lower Owyhee	17050110	13	Upper Middle Fork Salmon	17060205
10	Middle Owyhee	17050107	13	Upper Salmon	17060201
10	Middle Snake-Payette	17050115	14	Bitterroot	17010205
10	Middle Snake-Succor	17050103	14	Fisher	17010102
10	Upper Malheur	17050116	14	Flathead Lake	17010208
10	Upper Owyhee	17050104	14	Lower Clark Fork	17010213
10	Upper Snake-Rock	17040212	14	Lower Flathead	17010212
10	Weiser	17050124	14	Lower North Fork Clearwater	17060308
10	Willow	17050119	14	Middle Clark Fork	17010204
11	Brownlee Reservoir	17050201	14	Moyie	17010105
11	Hell's Canyon	17060101	14	South Fork Coeur d'Alene	17010302
11	Imnaha	17060102	14	St. Joe	17010304
11	Lower Grande Ronde	17060106	14	Stillwater	17010210
11	Lower Snake-Asotin	17060103	14	Upper Coeur d'Alene	17010301
11	Middle Fork John Day	17070203	14	Upper Kootenai	17010101
11	North Fork John Day	17070202	14	Upper North Fork Clearwater	17060307
11	Powder	17050203	14	Yaak	17010103
11	Upper Crooked	17070304	15	Blackfoot	17010203
11	Upper Grande Ronde	17060104	15	Flint-Rock	17010202
11	Upper John Day	17070201	15	Middle Fork Flathead	17010207
11	Wallowa	17060105	15	North Fork Flathead	17010206
12	Little Salmon	17060210	15	South Fork Flathead	17010209
12	Lochsa	17060303	15	Swan	17010211
12	Lower Salmon	17060209	16	Beaver-Camas	17040214
12	Lower Selway	17060302	16	Big Lost	17040218
12	Middle Fork Clearwater	17060304	16	Birch	17040216
12	Middle Fork Payette	17050121	16	Lemhi	17060204
12	Middle Salmon-Chamberlain	17060207	16	Little Lost	17040217
12	Boise-Mores	17050112	16	Medicine Lodge	17040215
12	North and Middle Forks Boise	17050111	16	Middle Salmon Panther	17060203
12	North Fork Payette	17050123	16	Pahsimeroi	17060202
12	Payette	17050122	16	Upper Clark Fork	17010201
12	South Fork Boise	17050113	16	Upper Henry's	17040202
12	South Fork Clearwater	17060305			

Table 2—Bailey province and Omernik ecoregion membership of sampled subbasins[a] of the midscale ecological assessment of the interior Columbia River basin[b]

Subbasin[c]	4th code HUC	Samples	State	Bailey province	Omernik ecoregion
(1) Pend Oreille	17010216	8	WA	M333—Northern Rocky Mountain	Northern Rockies
(2) Kettle	17020002	5	WA	M333—Northern Rocky Mountain	Northern Rockies
(3) San Poil	17020004	6	WA	M333—Northern Rocky Mountain	Northern Rockies
(4) Methow	17020008	17	WA	M242—Cascade	Cascades
(5) Wenatchee	17020011	11	WA	M242—Cascade	Cascades
(6) Upper Yakima	17030001	10	WA	M242—Cascade	Cascades
(7) Naches	17030002	9	WA	M242—Cascade	East-side Cascades slopes and foothills
(8) Lower Yakima	17030003	8	WA	M242—Cascade	Columbia basin
(9) Palouse	17060108	7	WA	331—Great Plains-Palouse Dry Steppe	Columbia basin
(9) Palouse	17060108	2	ID	331—Great Plains-Palouse Dry Steppe	Columbia basin
(10) Lower Grande Ronde	17060106	9	OR	M332—Middle Rocky Mountain	Blue Mountains
(11) Upper Grande Ronde	17060104	9	OR	M332—Middle Rocky Mountain	Blue Mountains
(12) Wallowa	17060105	7	OR	M332—Middle Rocky Mountain	Blue Mountains
(13) Burnt	17050202	6	OR	M332—Middle Rocky Mountian	Blue Mountains and Snake River basin and high desert
(14) Upper John Day	17070201	11	OR	M332—Middle Rocky Mountain and 342—Intermountain Semidesert	Blue Mountains
(15) Lower John Day	17070204	16	OR	M332—Middle Rocky Mountain and 342—Intermountain Semidesert	Columbia basin and Blue Mountains
(16) Lower Crooked	17070305	6	OR	M332—Middle Rocky Mountain and M242—Cascade	Blue Mountains and Snake River basin and high desert and east-side Cascades slopes and foothills
(17) Upper Deschutes	17070301	10	OR	M242—Cascade	East-side Cascades slopes and foothills
(18) Little Deschutes	17070302	6	OR	M242—Cascade	East-side Cascades slopes and foothills
(19) Silvies	17120002	4	OR	M332—Middle Rocky Mountain	Blue Mountains and Snake River basin and high desert

Table 2—Bailey province and Omernik ecoregion membership of sampled subbasins[a] of the midscale ecological assessment of the interior Columbia River basin[b] (continued)

Subbasin[c]	4th code HUC	Samples	State	Bailey province	Omernik ecoregion
(20) Donner und Blitzen	17120003	4	OR	342—Intermountain Semidesert	Snake River basin and high desert
(21) Crooked Rattlesnake	17050109	7	OR	342—Intermountain Semidesert	Snake River basin and high desert
(22) Lost	18010204	5	OR	M261-Sierran	East-side Cascades slopes and foothills and Snake River basin and high desert
(22) Lost	18010204	4	CA	M261-Sierran	East-side Cascades slopes and foothills and Snake River basin and high desert
(23) Upper Klamath Lake	18010203	4	OR	M261—Sierran and M242—Cascade	East-side Cascades slopes and foothills
(24) Big Wood	17040219	6	ID	342—Intermountain Semidesert and M332—Middle Rocky Mountain	Northern Rockies and Snake River basin and high desert
(25) Blackfoot (Montana)	17010203	16	MT	M332—Middle Rocky Mountain	Northern Rockies and Montana valley and Foothill prairies
(26) Bitterroot	17010205	8	MT	M332—Middle Rocky Mountain and M333—Northern Rocky Mountain	Northern Rockies and Montana valley and Foothill prairies
(27) Boise-Mores	17050112	3	ID	M332—Middle Rocky Mountain	Northern Rockies and Snake River basin and high desert
(28) Flint Rock	17010202	7	MT	M332—Middle Rocky Mountain	Northern Rockies and Montana valley and Foothill prairies
(29) Lake Walcott	17040209	9	ID	342—Intermountain Semidesert	Snake River basin and high desert and Northern Great Basin and range
(30) Lemhi	17060204	6	ID	M332—Middle Rocky Mountain	Northern Rockies and Snake River basin and high desert
(31) Lochsa	17060303	7	ID	M333—Northern Rocky Mountain and M332—Middle Rocky Mountain	Northern Rockies
(32) Lower Flathead	17010212	14	MT	M333—Northern Rocky Mountain	Northern Rockies and Montana valley and Foothill prairies
(33) Lower Henry's	17040203	3	ID	M331—Southern Rocky Mountain and 342—Intermountain Semidesert	Middle Rockies and Snake River basin and high desert
(33) Lower Henry's	17040203	1	WY	M331—Southern Rocky Mountain	Middle Rockies and Snake River basin and high desert

Table 2—Bailey province and Omernik ecoregion membership of sampled subbasins[a] of the midscale ecological assessment of the interior Columbia River basin[b] (continued)

Subbasin[c]	4th code HUC	Samples	State	Bailey province	Omernik ecoregion
(34) Medicine Lodge	17040215	5	ID	342—Intermountain Semidesert and M332—Middle Rocky Mountain	Northern Rockies and Snake River basin and high desert
(35) Palisades	17040104	5	ID	M331—Southern Rocky Mountain	Middle Rockies
(35) Palisades	17040104	1	WY	M331—Southern Rocky Mountain	Middle Rockies
(36) Snake Headwater	17040101	8	WY	M331—Southern Rocky Mountain	Middle Rockies
(37) South Fork Clearwater	17060305	6	ID	M332—Middle Rocky Mountain	Northern Rockies and Columbia basin
(38) South Fork Salmon	17060208	7	ID	M332—Middle Rocky Mountain	Northern Rockies
(39) Swan	17010211	4	MT	M333—Northern Rocky Mountain	Northern Rockies
(40) Upper Owyhee	17050104	12	ID	342—Intermountain Semidesert	Snake River basin and high desert and Northern Great Basin and range
(41) Upper Coeur d'Alene	17010301	5	ID	M333—Northern Rocky Mountain	Northern Rockies
(42) Upper Middle Fork	17060205	9	ID	M332—Middle Rocky Mountain	Northern Rockies
(43) Yaak	17010103	4	MT	M333—Northern Rocky Mountain	Northern Rockies

[a] 337 subwatersheds were sampled in 43 subbasins.

[b] See also figure 3.

[c] Numbers in parentheses identify subbasins shown in figure 3.

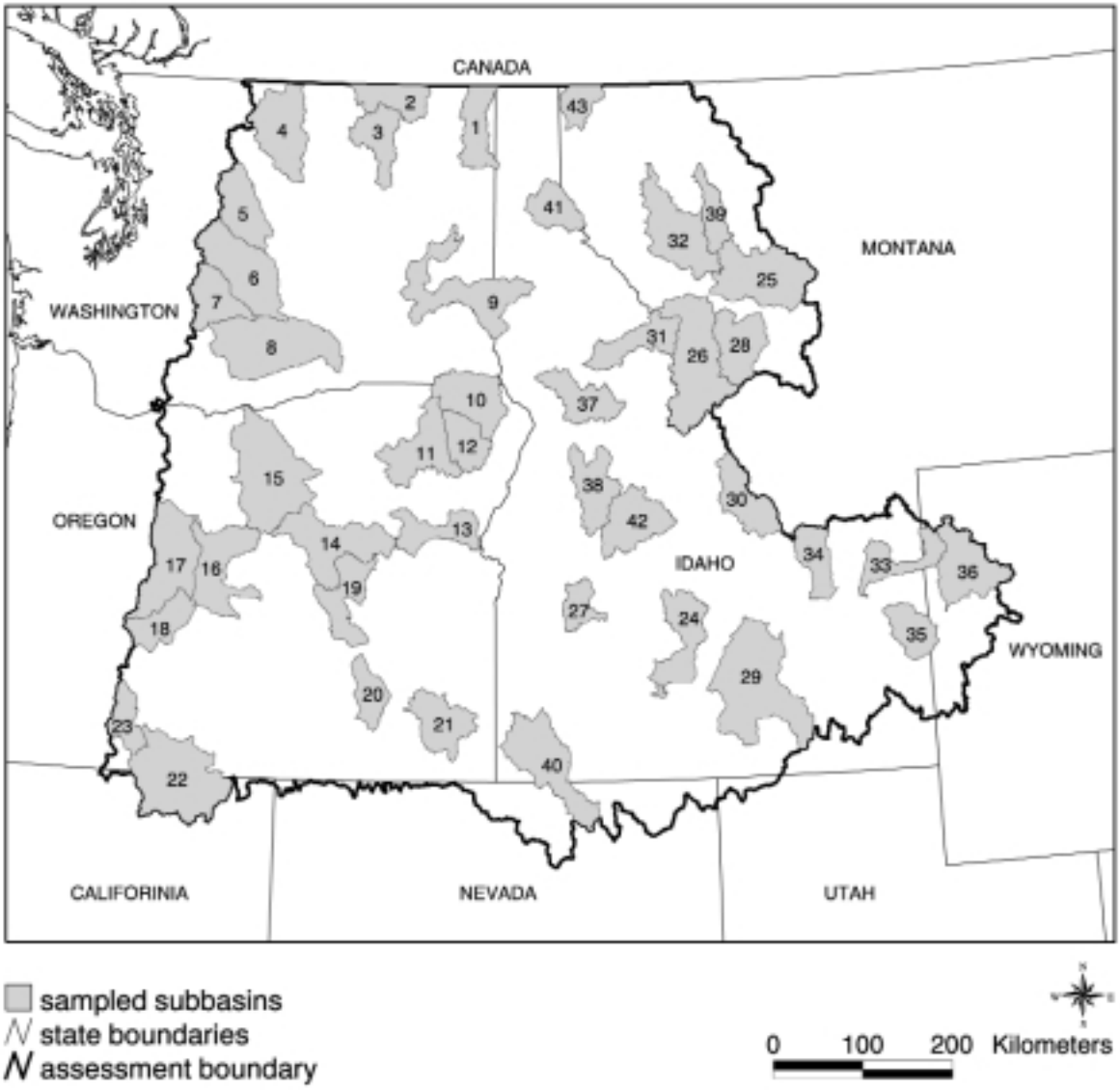

Figure 3—Sampled subbasins of the midscale assessment of the interior Columbia River basin (see also table 2). The assessment area included the portion of the Columbia River basin occurring in the United States east of the crest of the Cascade Range. Subbasins in the upper reaches of the Klamath River basin and the Northern Great Basin also were included to fully represent conditions in eastern Oregon and Washington, Idaho, and western Montana.

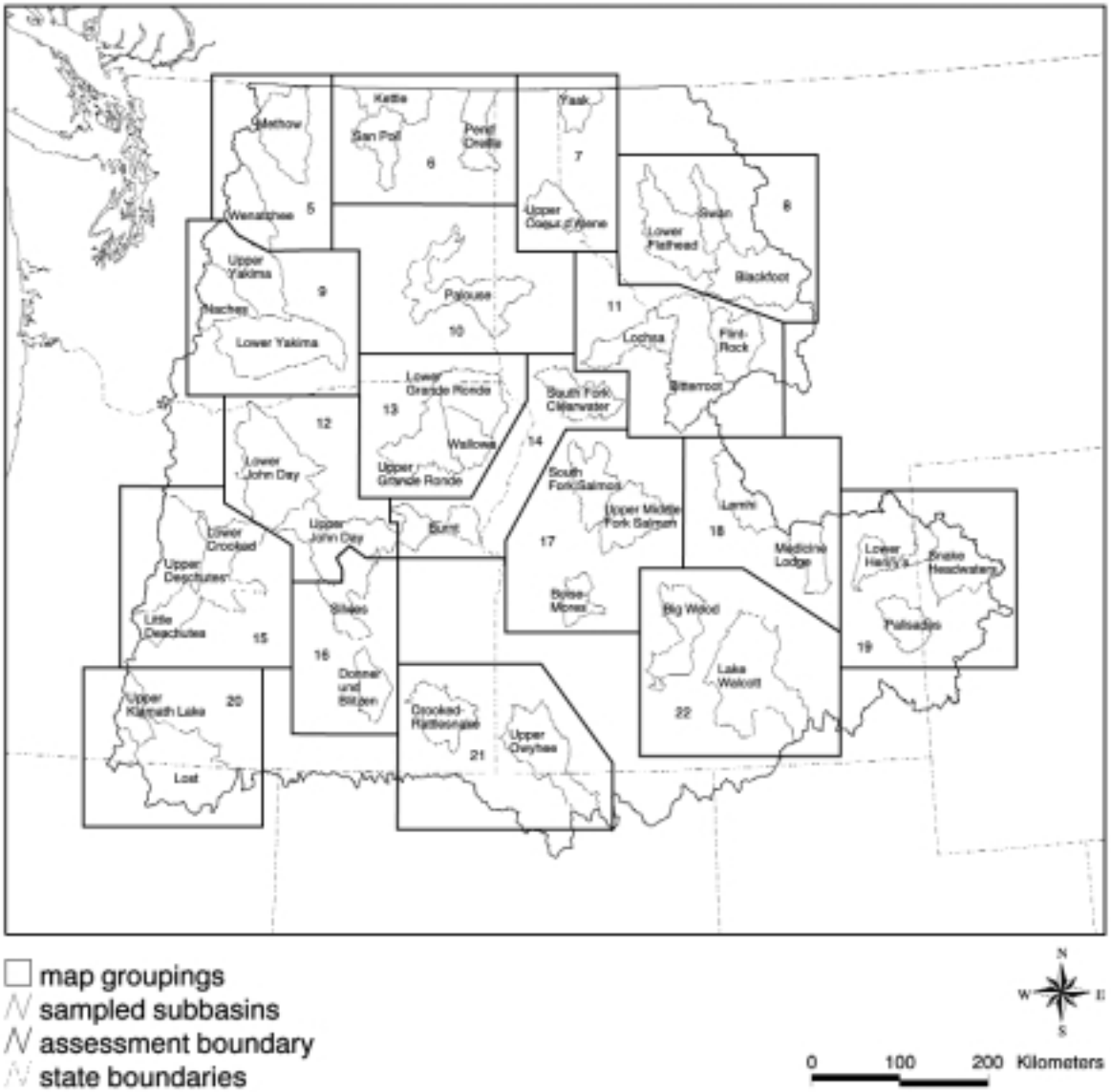

Figure 4—Map groupings of subbasins sampled in the midscale ecological assessment of the interior Columbia River basin. Subbasins were separated for ease of mapping into 18 groups. Sampled watersheds are shown by subbasin group in figures 5 to 22.

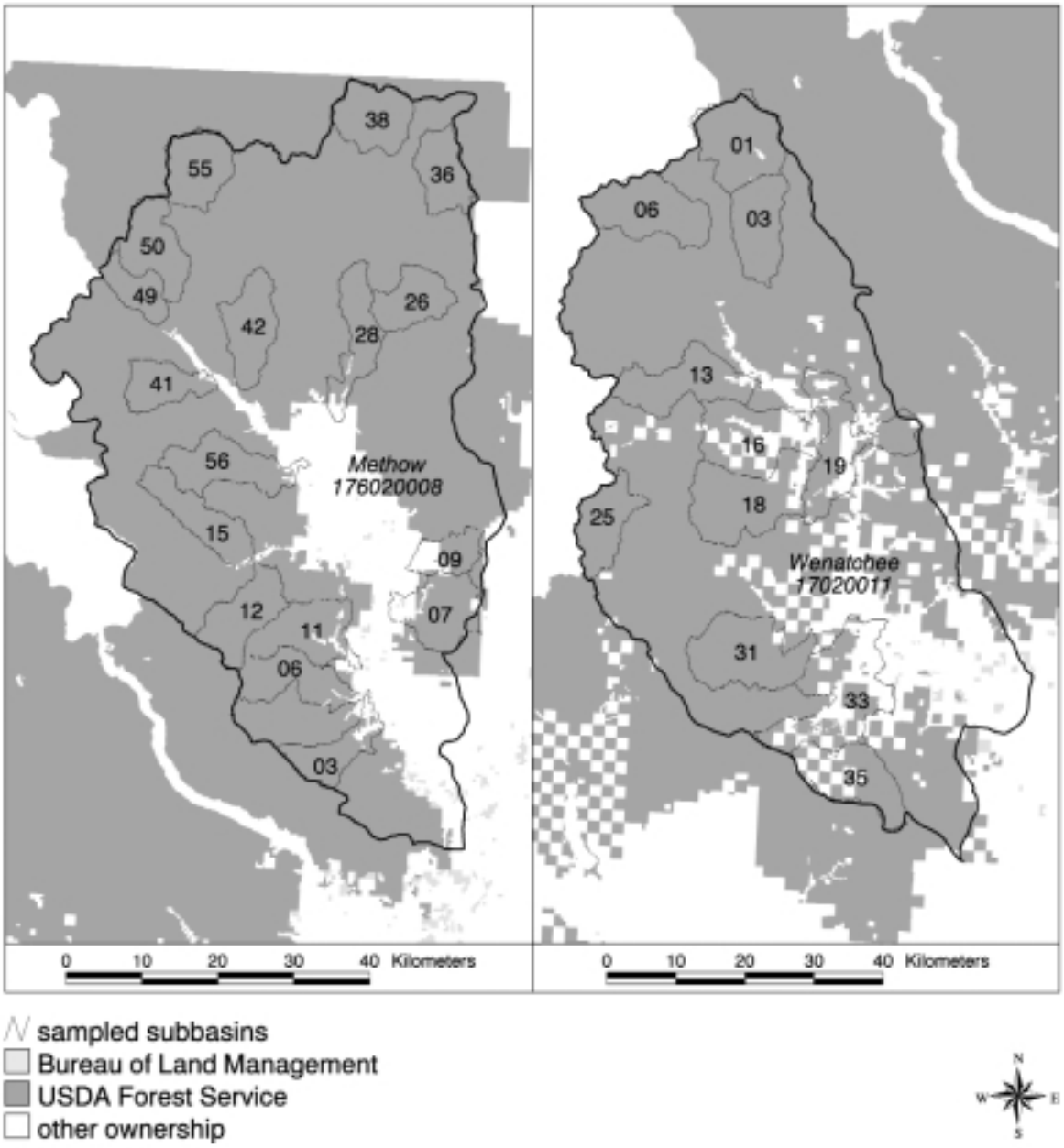

Figure 5—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Methow and Wenatchee subbasins of Washington for the midscale ecological assessment of the interior Columbia River basin.

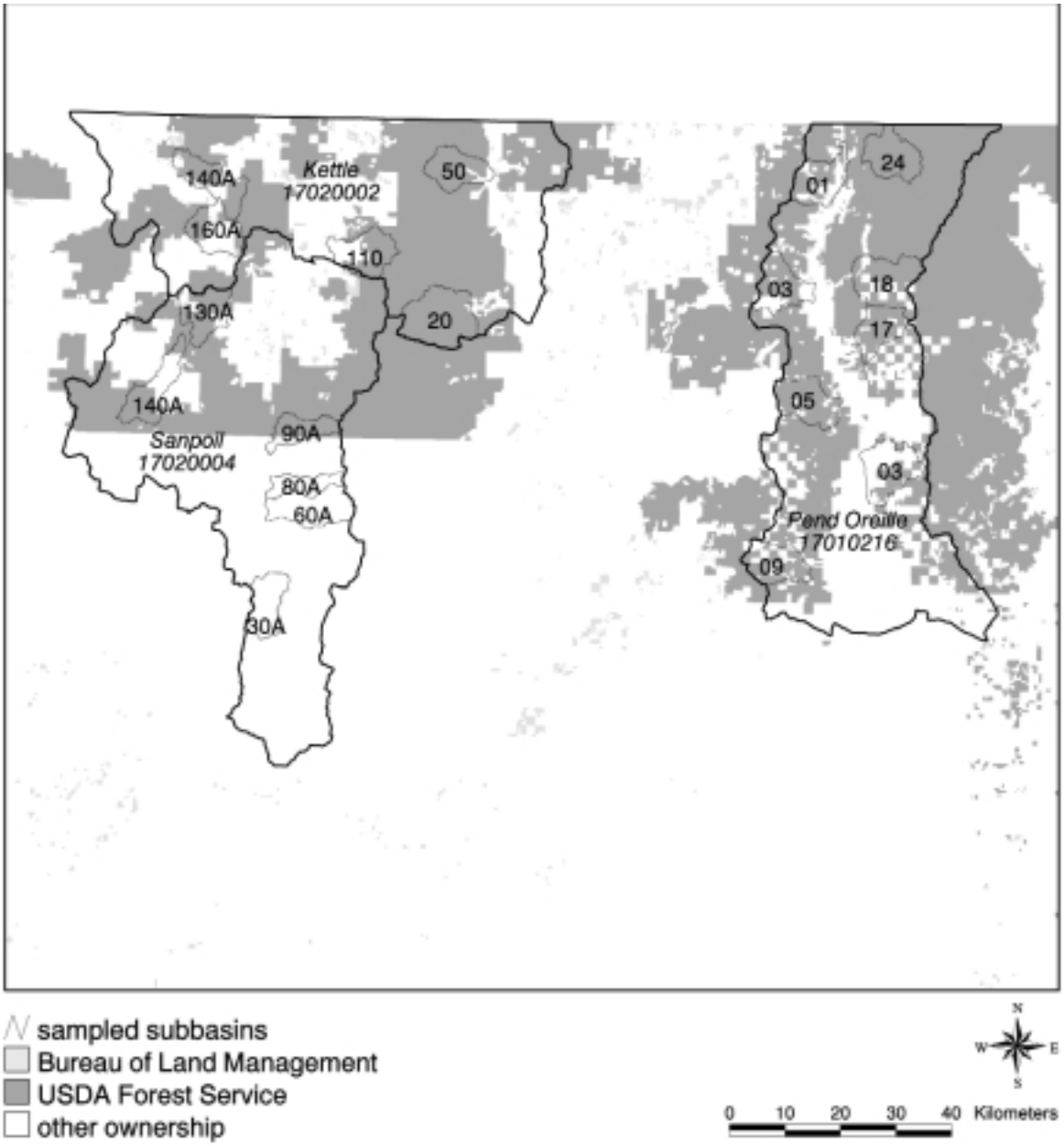

Figure 6—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Kettle, Sanpoil, and Pend Oreille subbasins of Washington for the midscale ecological assessment of the interior Columbia River basin.

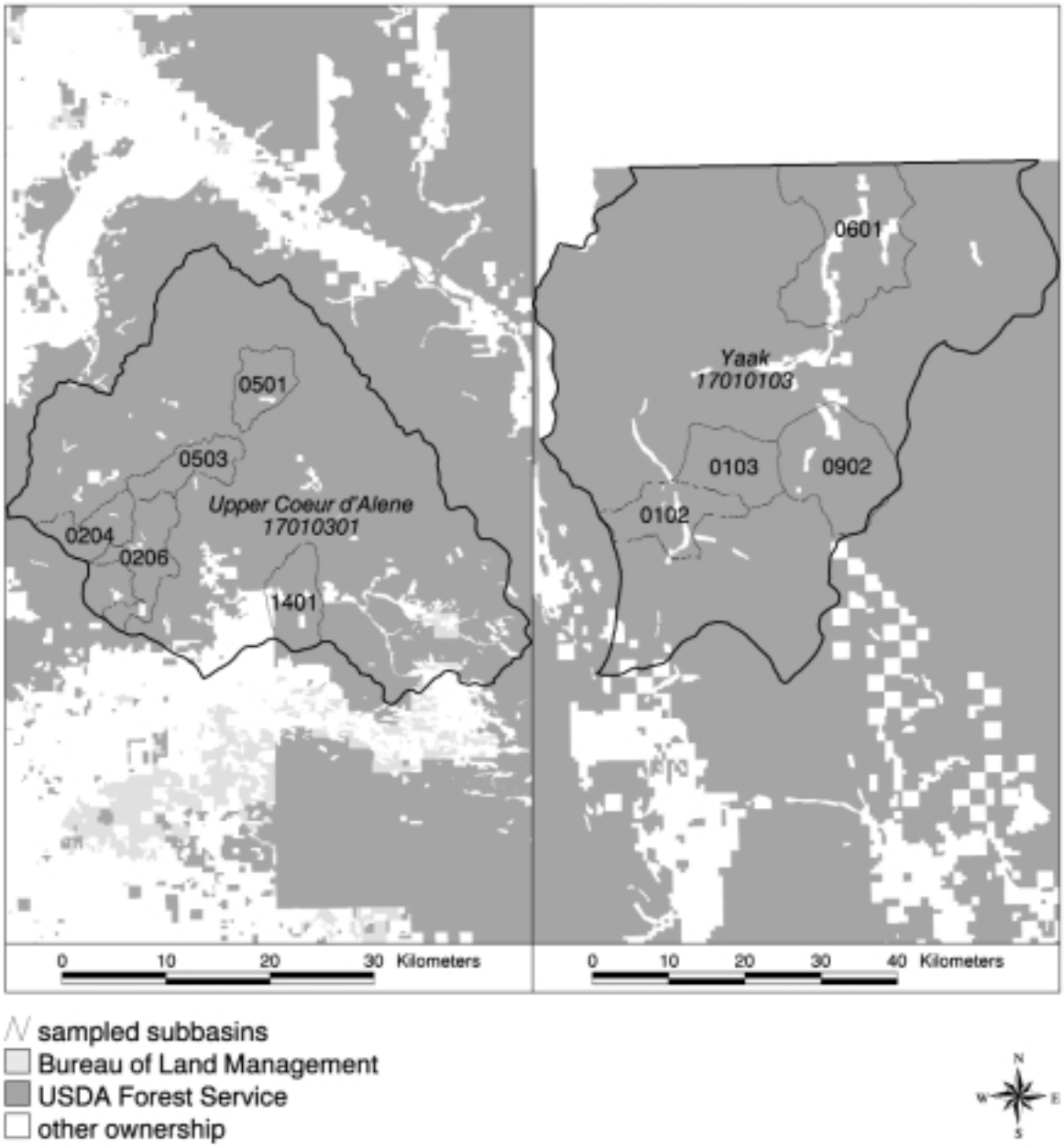

Figure 7—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Upper Coeur d'Alene and Yaak subbasins of Idaho and Montana for the midscale ecological assessment of the interior Columbia River basin.

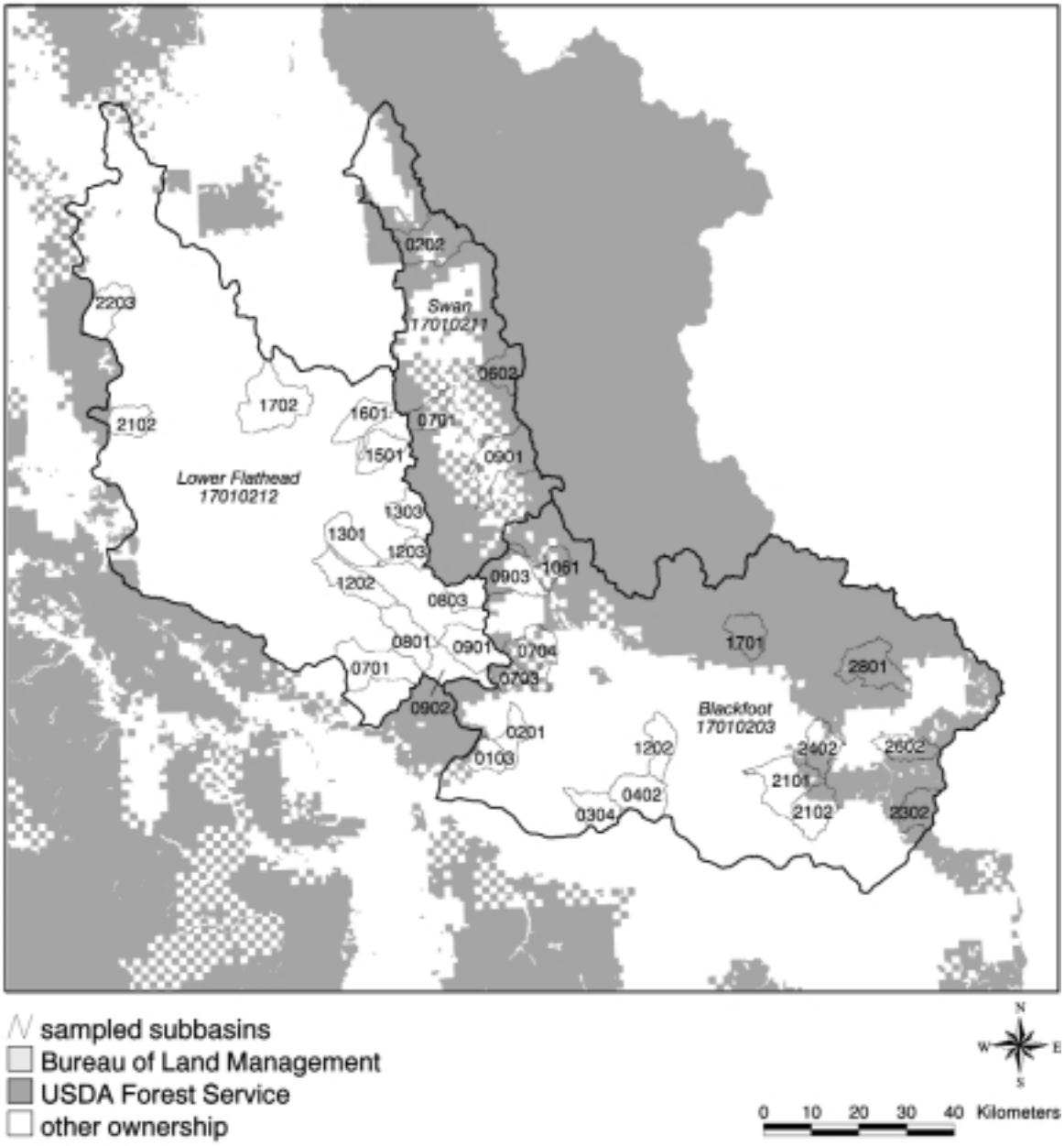

Figure 8—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Lower Flathead, Swan, and Blackfoot subbasins of Montana for the midscale ecological assessment of the interior Columbia River basin.

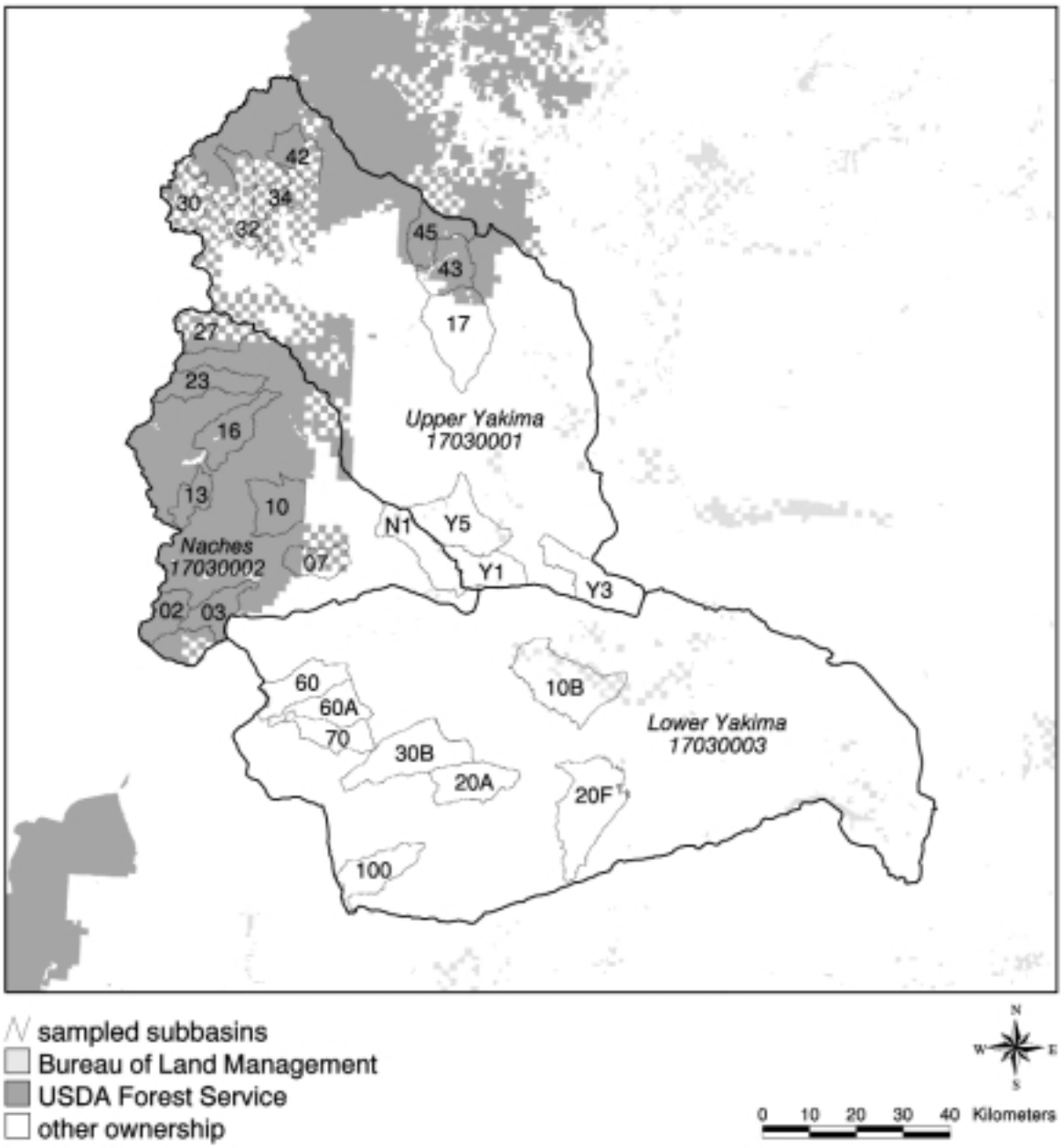

Figure 9—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Upper Yakima, Naches, and Lower Yakima subbasins of Washington for the midscale ecological assessment of the interior Columbia River basin.

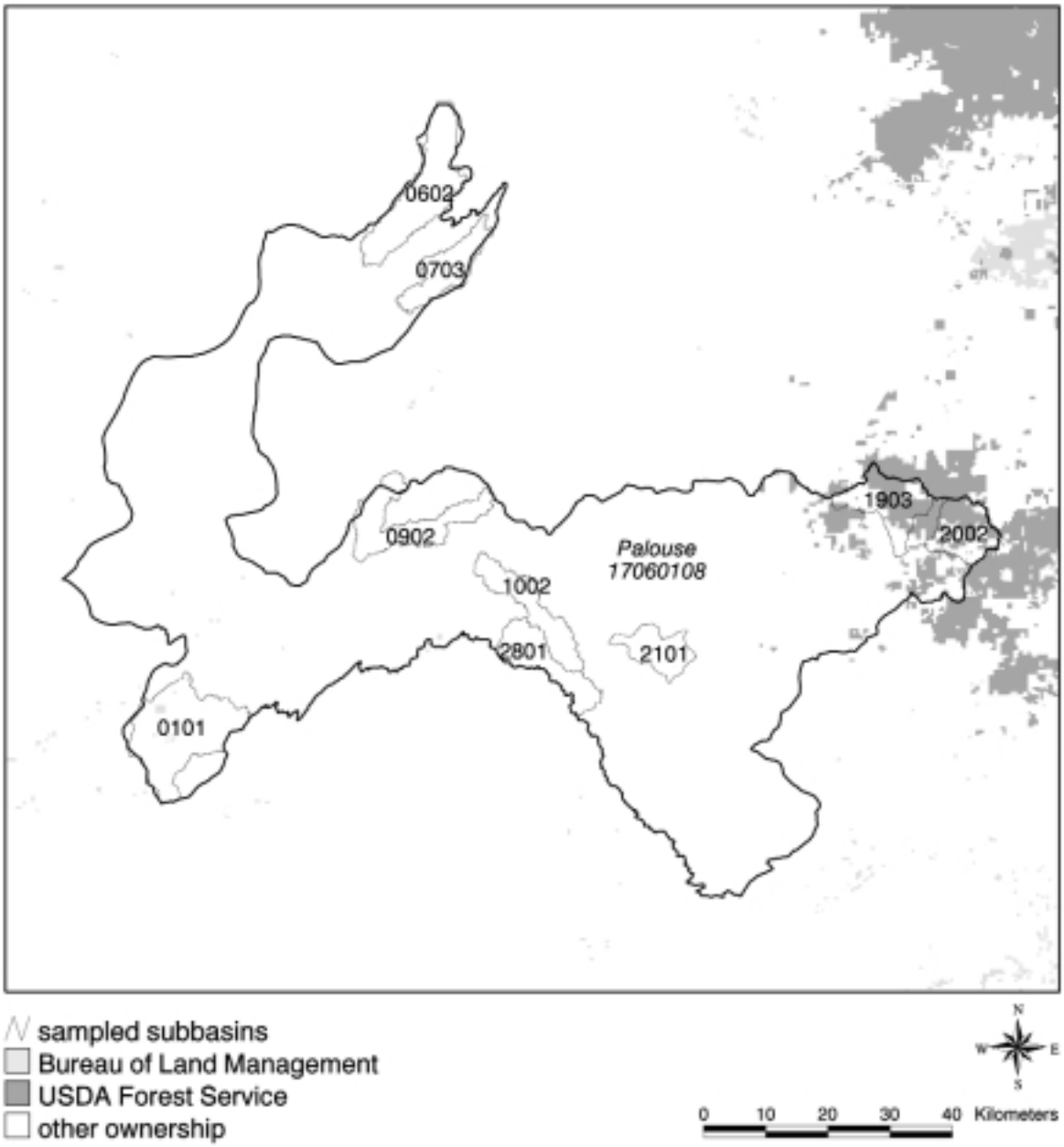

Figure 10—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Palouse subbasin of Idaho and Washington for the midscale ecological assessment of the interior Columbia River basin.

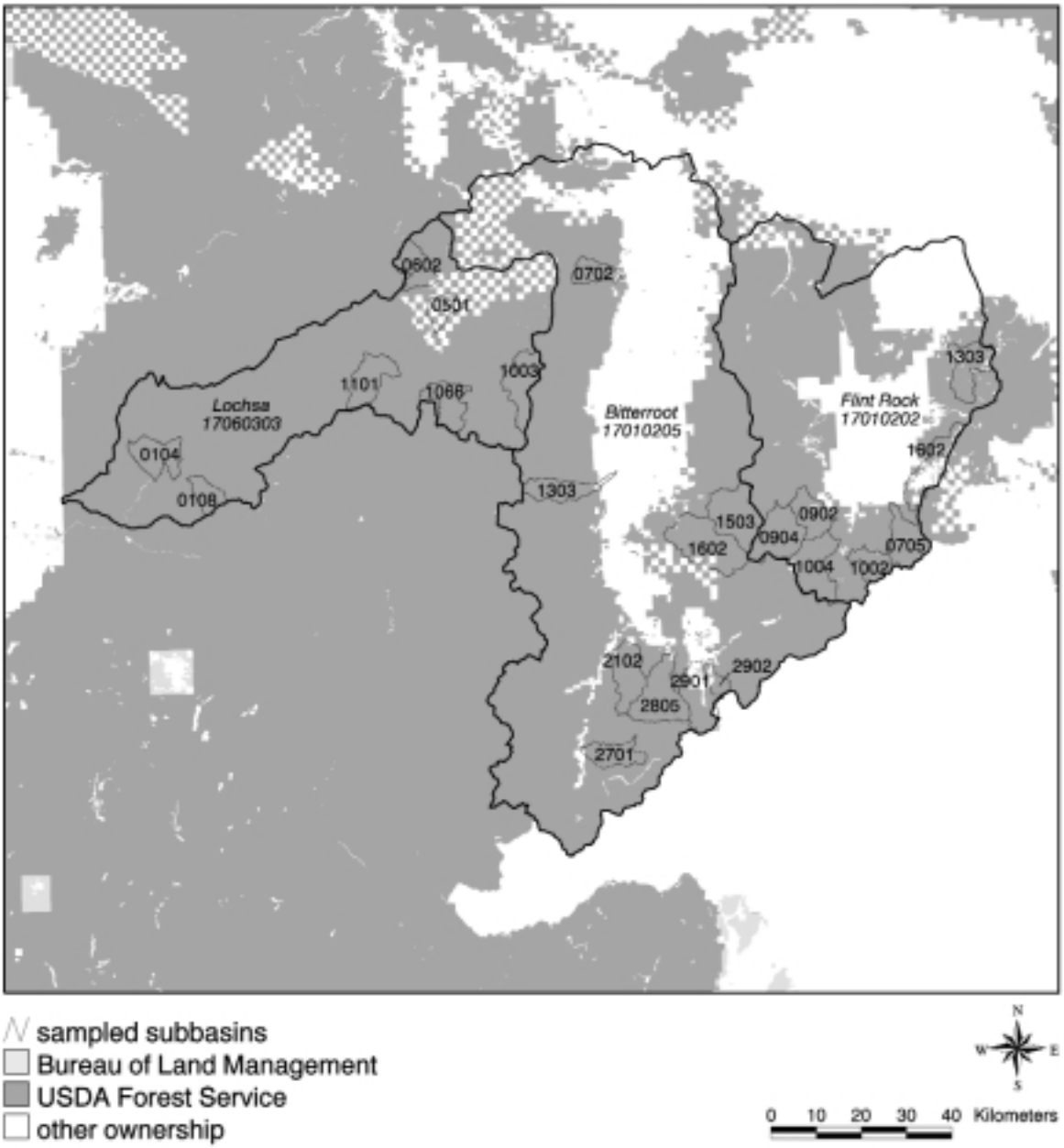

Figure 11—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Lochsa, Flint Rock, and Bitterroot subbasins of Idaho and Montana for the midscale ecological assessment of the interior Columbia River basin.

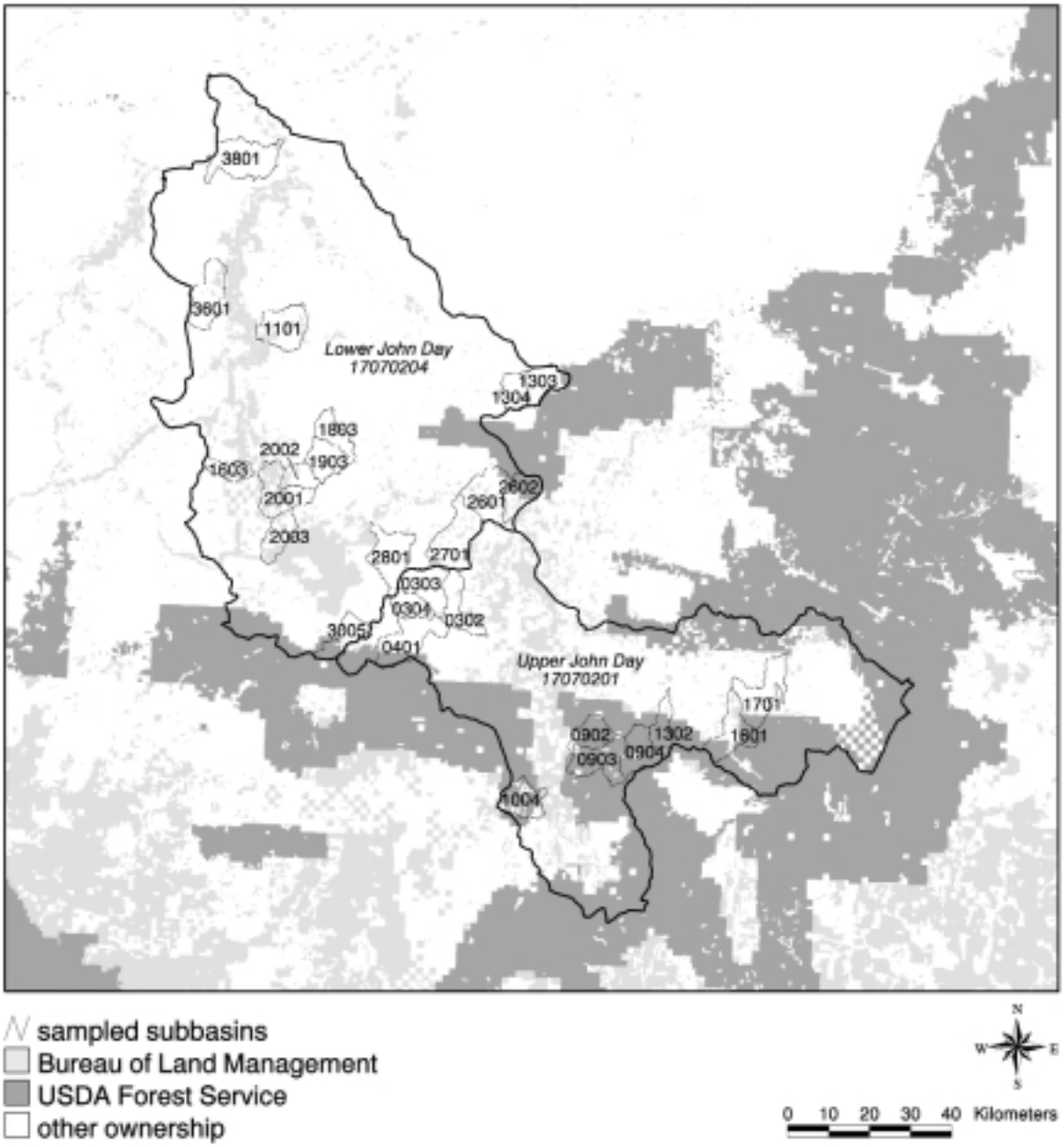

Figure 12—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Upper and Lower John Day subbasins of Oregon for the midscale ecological assessment of the interior Columbia River basin.

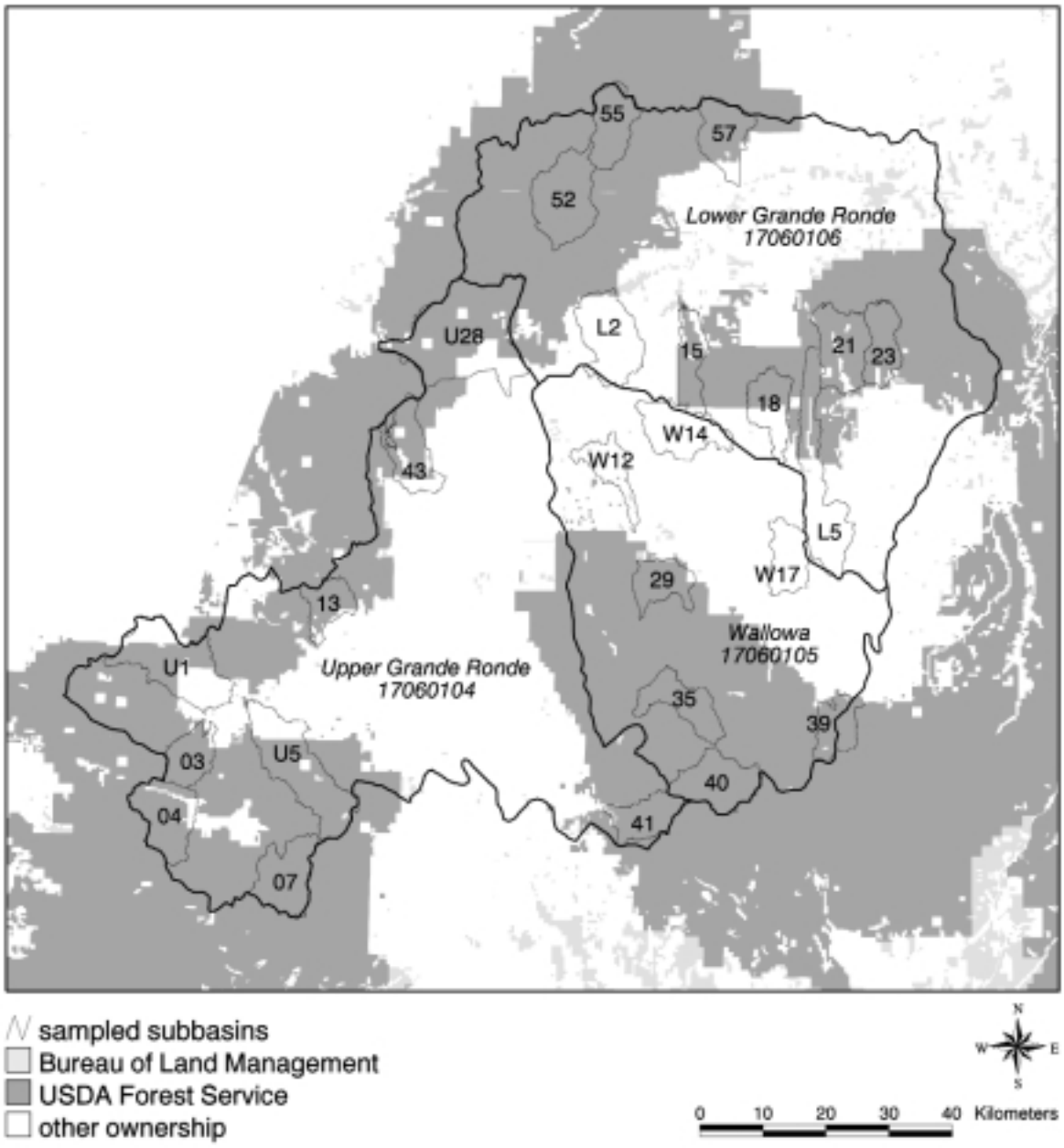

Figure 13—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Upper Grande Ronde, Wallowa, and Lower Grande Ronde subbasins of Oregon and Washington for the midscale ecological assessment of the interior Columbia River basin.

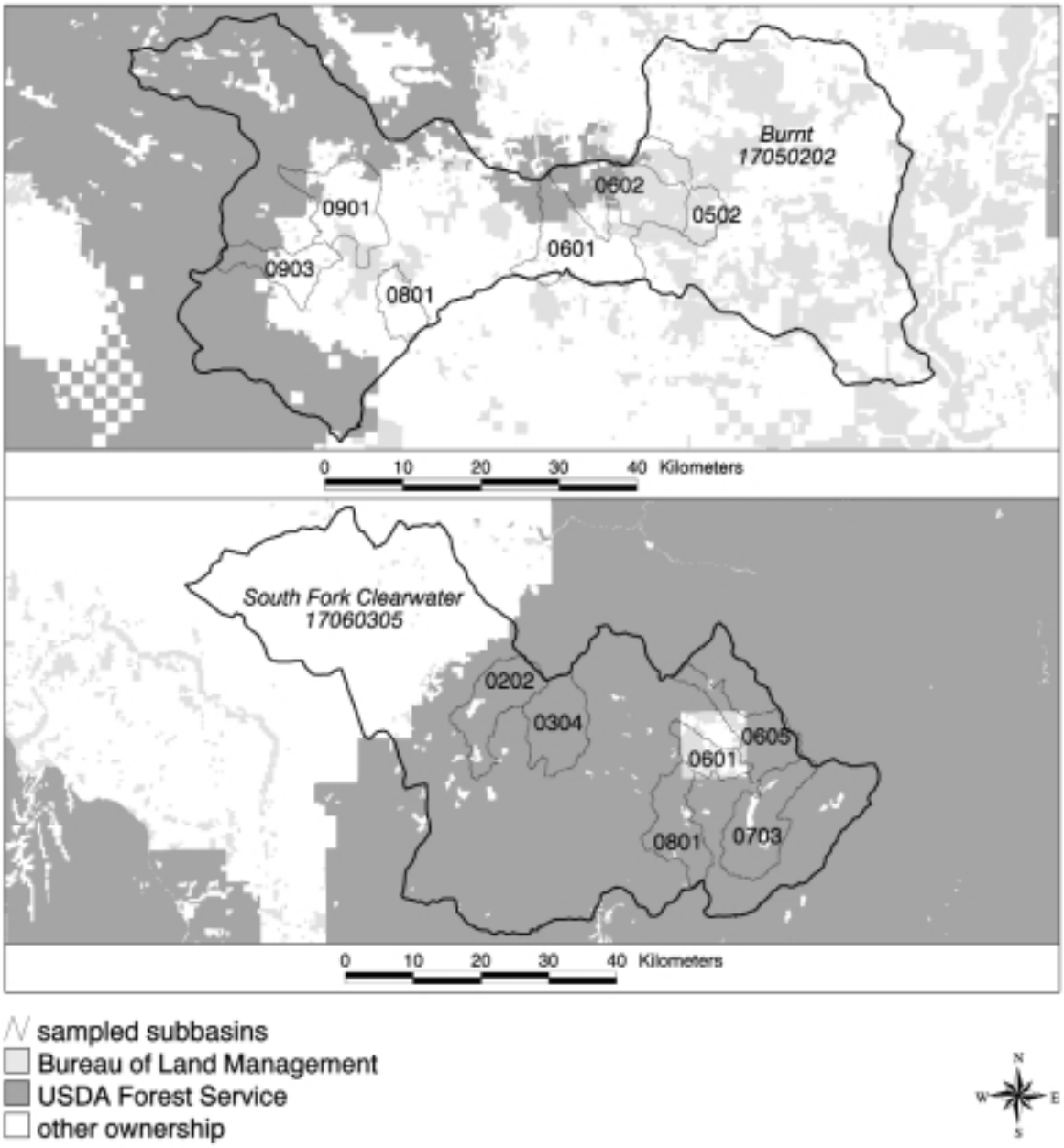

Figure 14—Subwatersheds on USDA Forest Service, Bureau of Land Management, and other ownerships sampled in the Burnt and South Fork Clearwater subbasins of Oregon and Idaho for the midscale ecological assessment of the interior Columbia River basin.