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An Initial Evaluation of Potential Options for Managing Riparian Reserves of the Aquatic Conservation Strategy of the Northwest Forest Plan

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Abstract

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The Aquatic Conservation Strategy (ACS) of the Northwest Forest Plan guides management of riparian and aquatic ecosystems on federal lands in western Oregon, western Washington, and northern California. We applied new scientific findings and tools to evaluate two potential options, A and B, for refining interim riparian reserves to meet ACS goals and likely challenges of climate change while supporting other management goals, including timber production. Interim riparian reserves are retained in late-successional reserves and other special land designations in the options. In lands designated as matrix, the area for aquatic conservation extends upslope one site-potential tree-height along all streams, divided into an inner zone devoted solely to achieving ACS goals and an outer zone managed to achieve ACS and other goals. Option A uses a fixed-width approach and option B a context-dependent approach, with partitioning of zones based on the ecological sensitivity of stream reaches. Based on simulations of the area of interim riparian reserves in six watersheds in western Oregon with lands managed by the Bureau of Land Management (BLM): (1) about 76 percent under option A and 72 percent under option B remain solely devoted to ACS goals; (2) 15 percent under option A and 19 percent under option B should be able to meet ACS goals and also contribute toward matrix goals such as timber production; and (3) 9 percent would be returned to matrix. A large percentage of streams with high ecological sensitivity occurred on nonfederal lands, a circumstance that merits further analysis in the context of landscape-scale considerations for biodiversity and recovery of species listed under the Endangered Species Act. Information needs remain with regard to the application and effectiveness of these options, and an adaptive management context is critical for continued improvement.

Keywords: Aquatic Conservation Strategy, interim riparian reserves, riparian management, context-dependent buffers.

Executive Summary

The Aquatic Conservation Strategy (ACS) of the Northwest Forest Plan (NWFP) was designed to maintain and improve the ecological processes in aquatic ecosystems for Pacific salmon (*Oncorhynchus* spp.), other native fish, aquatic and riparian-dependent organisms, and water quality. A key element of the ACS was a system of interim riparian reserves of two site-potential tree-heights on fish-bearing streams, and one site-potential tree-height on non-fish-bearing streams. These reserves were adopted in 1994 as part of the NWFP; it was expected that they would be revised during implementation based on scientifically sound reasoning but, in general, such revisions have not been made.

We explore the application of new scientific findings and tools to do an initial ecological evaluation of two potential options for managing riparian and aquatic ecosystems in a way that could meet ACS goals, and the likely challenges of climate change, while also allowing the fulfillment of other management goals, including timber production. The options evaluated here were informed by new research, tools, and concepts, including: (1) the influence of the width of riparian area on microclimate; (2) movement of amphibians along non-fish-bearing streams; (3) the distance to and sources of wood for fish-bearing streams; (4) **intrinsic potential** (IP), a concept for assessing the capability of a given set of geomorphic conditions in a stream reach to provide habitat for selected species of Pacific salmon; (6) NetMap, a geo-spatial platform for watershed analysis that can, among other things, identify the location of key ecological processes that influence aquatic and riparian ecosystems on the landscape and in the stream network; and (7) concepts for managing riparian ecosystems and the activities that affect them, such as ecological forestry and tree-tipping.

Under both of the potential options for managing the riparian reserves of the ACS evaluated here, current interim riparian reserves of two site-potential tree-heights along fish-bearing streams and one site-potential tree-height along non-fish-bearing streams are retained in late-successional reserves and other special land designations. In lands allocated as matrix under the NWFP, the area of interest for aquatic conservation, which we refer to as the riparian conservation area, extends upslope from the stream for a distance equal to the height of one site-potential tree along fish-bearing and non-fish-bearing streams under both options. **Riparian conservation areas** are divided into an inner and an outer zone; the inner zone is devoted solely to achieving goals of the ACS, while the outer zone would be managed to achieve ACS and other management goals, which could include timber production. If timber production is implemented in the outer zone, ecological

forestry prescriptions with significant amounts of retention would guide harvesting activities. The options differ in how the riparian conservation area is partitioned between inner and outer zones. Option A uses a fixed-width approach to partition the zones. Option B uses a context-dependent approach based on four important characteristics of each stream reach—susceptibility to surface erosion, debris flows, thermal loading, and habitat potential for target fish species—to determine the appropriate width of the inner zone. Both options are limited to stands ≤80 years of age, and "tree-tipping" is used throughout the riparian conservation area to ensure that harvest does not negatively affect wood recruitment to the stream.

We simulated and compared the two potential options to the existing interim riparian reserves across six watersheds that contain approximately 30 percent of matrix lands managed by the Bureau of Land Management (BLM) in western Oregon. Under option A, we found that an average of 54 percent of the interim riparian reserves on BLM matrix across the study watersheds would continue to be managed solely for ACS goals; under option B, an estimated average of 46 percent would be managed solely for those goals. Also, an estimated average of 29 percent of interim riparian reserves on BLM matrix under option A and 36 percent under option B would achieve ACS goals along with other potential goals, which could include timber production, and 18 percent could be returned to the terrestrial prescriptions of the NWFP. Interim riparian reserves in late-successional and other reserve allocations, which cover approximately half of the BLM lands in western Oregon, would remain unchanged under both options. Assuming that half of the interim riparian reserves on BLM lands in western Oregon would remain unchanged, and applying our study estimates of changes in matrix under the two modeled options to the entire BLM matrix in western Oregon, we estimate that about 76 percent of the interim riparian reserves under option A and 72 percent under option B would remain solely devoted to ACS goals. Under options A and B, respectively, an additional estimated 15 percent and 19 percent of the interim riparian reserves on BLM lands in western Oregon would likely meet ACS goals and may also provide opportunity for achievement of matrix goals including limited timber production. Under both options, reduction of the width of the riparian reserve along fish-bearing streams to one tree-height would return an estimated 9 percent of interim riparian reserves to matrix on these lands.

Because our analysis took a "whole-watershed" approach, we identified important stream segments for aquatic ecosystem conservation on all lands, federal and nonfederal. We found that federal lands contain some, but not all, streams with high ecological sensitivity, and determined that many ecologically sensitive streams occur on nonfederal lands. This finding merits further analysis in the context of landscape-scale considerations for biodiversity and the recovery of threatened or endangered species.

Our analysis is not intended to suggest or imply that the two potential options described here are the only alternatives for managing riparian ecosystems. And, just as with the interim riparian reserves, these or any other options should not be viewed as immutable. Our analysis provides a framework for understanding recent scientific information and how it might be used to develop options for managing interim riparian reserves other than as de facto reserves to meet the goals of the ACS, while allowing opportunities to achieve other goals such as timber production, and that also meet the challenges of climate change. Although new science has refined our understanding of the ecological processes that occur in the interim riparian reserves, uncertainties and information needs remain. Thus, an adaptive management context is critical for continual improvement and further evaluation.

Contents

Introduction

Across the area of the Northwest Forest Plan (NWFP) (USDA and USDI 1994), management of riparian and aquatic ecosystems is a major focus of and challenge to federal land-management agencies. These ecosystems occupy about 40 percent of the federal land base, and on federal forest lands within the range of the northern spotted owl (*Strix occidentalis caurina*), the Aquatic Conservation Strategy (ACS) guides federal agencies in their management. The goals of the ACS are to: (1) maintain and restore the ecological processes that create and maintain habitat for native aquatic and riparian-dependent organisms; and (2) provide sources of high-quality water, recreation, and other ecological benefits (USDA and USDI 1994). Recovery of species listed under the Endangered Species Act is tightly tied to successfully meeting these goals.

The riparian reserve network, a cornerstone of the ACS, defines the spatial extent of the riparian ecosystem based on the distance from the stream at which key ecological processes occur. Interim riparian reserves of two site-potential tree-heights on fish-bearing streams and one site-potential tree-height on non-fish-bearing streams were established when the NWFP was adopted. We focus on riparian reserves here because their interim boundaries could be adjusted based on "scientifically sound reasoning" and site-specific information resulting from watershed analysis (FEMAT 1993, p. V-35), thus enabling an improved reserve design to better meet ACS objectives (FEMAT 1993, p. V-44) and the broader goals of the NWFP. However, there have been only minor boundary adjustments, especially within one tree-height of streams (Reeves 2006), since adoption of the NWFP in 1994 (Baker et al. 2006, Reeves et al. 2006).

Everest and Reeves (2007) found no scientific evidence that the default prescriptions in the Northwest Forest Plan provided more protection than necessary to meet stated riparian management goals. However, they also stated that additional alternative riparian management strategies that meet ASC objectives, while providing opportunities for other management objectives, could be implemented and evaluated. We apply findings and results of scientific studies published since FEMAT (1993) in an evaluation of two potential options for management of the interim riparian reserves that meet ASC objectives while providing opportunities for other management objectives, then examine projected consequences in six watersheds in western Oregon that contain land managed by the Bureau of Land Management (BLM). Considering only lands allocated as matrix, where timber production is one of the goals of the NWFP, these options evaluate potential adjustments to riparian reserve boundaries and management strategies within the area currently designated as interim riparian reserves. In both options, the other components of the ACS (key watersheds, monitoring, and standards and guidelines) are maintained across all allocations, and existing interim riparian reserves are maintained in land allocations outside of matrix.

Both potential options focus on the area within one site-potential tree-height of fish-bearing and non-fish-bearing streams in matrix and divide this area into an inner zone and outer zone with different management objectives and activities. The inner zone is devoted solely to achieving ACS goals; the outer zone is managed to achieve ACS goals as well as other management goals, which could include timber production. The first option uses a fixed-width approach to delineate the two zones, and the second uses a context-dependent approach based on the ecological characteristics of each stream reach. These options fall within the bounds of what was expected by the developers of the ACS (FEMAT 1993) and the Record of Decision (ROD) (USDA and USDI 1994).

As with any new approach to management, implementation and evaluation in an adaptive management context is imperative.

Our analysis provides a means to understand recent scientific information in the context of possible management options, and suggests ways this information might be used to develop new approaches for managing interim riparian reserves other than as de facto reserves. These analyses are not intended to suggest or imply that the two options evaluated here are the only ones for managing interim riparian reserves. In common with the interim riparian reserves, these or any other options should not be viewed as immutable, and as with any new approach to management, implementation and evaluation in an adaptive management context (Stankey et al. 2005) is imperative.

The Aquatic Conservation Strategy in the Northwest Forest Plan

Goals

The Aquatic Conservation Strategy is a regional strategy applied to aquatic and riparian ecosystems across the area covered by the NWFP. It seeks to prevent degradation of aquatic ecosystems and to restore and maintain water quality, habitat, and the ecological processes responsible for creating habitat for Pacific salmon (*Oncorhynchus* spp.) and other aquatic and riparian-dependent organisms, over broad landscapes of public lands administered by the U.S. Department of Agriculture Forest Service and the U.S. Department of the Interior Bureau of Land Management (USDA and USDI 1994). The ACS was developed during the analysis that led to the Northwest Forest Plan (FEMAT 1993), but its foundation was a refinement of earlier strategies: the Scientific Panel on Late-Successional Forest Ecosystems (“The Gang of Four”) (Johnson et al. 1991), PacFish (USDA 1992), and the Scientific Assessment Team (Thomas et al. 1993). In the short term (10 to 20 years), the ACS was designed to halt further declines in watershed condition, and to protect watersheds that currently had good-quality habitat and strong fish populations (FEMAT 1993). The long-term goal (100+ years) was to develop a network of functioning watersheds that support populations of fish and other aquatic and riparian-dependent organisms across the NWFP area (USDA and USDI 1994).

The ACS sets out five components to meet its goals and objectives: (1) watershed analysis; (2) riparian reserves; (3) key watersheds; (4) watershed restoration; and (5) standards and guidelines for management activities (USDA and USDI 1994). Each component is essential for the success of the ACS (USDA and USDI 1994), and any assessment must consider all five of these components in aggregate.

Riparian reserves were intended to define the outer boundaries of the riparian ecosystem, and encompass the portions of a watershed most tightly coupled with streams and rivers. Riparian areas provide the ecological functions and processes necessary to create and maintain habitat for aquatic and riparian-dependent organisms over time, dispersal corridors for a variety of terrestrial organisms, and connectivity of streams within watersheds (FEMAT 1993). The FEMAT scientists developed three riparian management scenarios (FEMAT 1993, p. V-37). Each scenario required a reserve width on fish-bearing streams equal to two times the height of a site-potential tree (minimum of 300 ft [91.4 m]), where a site-potential tree is defined as a tree that has attained the average maximum height possible given the conditions where it occurs (FEMAT 1993, p. V-32). The riparian management scenarios varied in their requirements for non-fish-bearing streams, ranging from a width equal to one-sixth of a site-potential tree-height (minimum of 25 ft [7.6 m]) to that of one site-potential tree-height (FEMAT 1993, p. V37). One scenario was integrated into each of the 10 landscape alternatives developed by the FEMAT scientists (FEMAT 1993).

The Secretaries of Interior and Agriculture chose FEMAT's option 9 as their preferred alternative, which called for a riparian reserve network that was two site-potential tree-heights wide on fish-bearing streams and one half of a site-potential tree-height on most non-fish-bearing streams. Interim boundaries of riparian reserves were extended to a full site-potential tree-height on all non-fish-bearing streams between the draft and final environmental impact statements (USDA and USDI 1994) to increase the likelihood of success of the ACS, and to provide additional protections for non-fish organisms that use the area near streams as habitat or migratory corridors (FEMAT 1993). Thinning to advance aquatic ecosystem values is allowed within the riparian reserves, but timber production is not a management goal (USDA and USDI 1994).

Watershed condition since implementation of the ACS—
To date, the ACS has met the goal of improving the ecological condition of watersheds across federal lands to which it applies (Lanigan et al. 2012, Reeves et al. 2006). After the first 10 years of implementation, the ecological condition of 65 percent of watersheds improved, 28 percent declined, and 7 percent remained unchanged (Reeves 2006, Reeves et al. 2006). After 15 years, ecological conditions had improved in 69 percent of the watersheds, and declined in 18 percent (Lanigan et al. 2012). The primary factors responsible for improvement were an increase in the number of large trees (>20 inches [51 cm] in diameter) in riparian areas and a reduction in road densities in watersheds. Watersheds in which conditions declined have recently experienced wildfires.

Underlying Principles and Concepts

We begin with a discussion of contemporary research findings that formed the foundation for designing both potential options in this report: (1) the dynamic nature of aquatic ecosystems in space and time, (2) the ecological importance of non-fish-bearing streams, and (3) the effects of timber harvest on microclimate and amphibians. Next, we discuss forest-management strategies that we incorporated into the options: (1) ecological forestry as described in Franklin and Johnson (2012) as a guide to silviculture, and (2) "tree-tipping" to compensate for potential loss in wood recruitment to streams.

Streams and associated aquatic ecosystems: dynamic in space and time—
Assessing potential ecological effects of management in riparian ecosystems is dependent on a number of factors. A critical though seldom explicitly recognized factor is the perspective on how streams and their associated aquatic ecosystems behave in space and time. One view holds that aquatic ecosystems tend to be in an equilibrium or steady state, and when disturbed they are expected to return to pre-disturbance conditions relatively quickly (Resh et al. 1988, Swanson et al. 1988). Biological (Vannote et al. 1980) and physical conditions (Rosgen 1994) are presumed to be relatively constant through time and to be "good" (barring human interference) in all systems at the same time. Conditions in aquatic systems with little or no human influence, particularly those associated with old-growth forest, are understood to have the most favorable conditions for fish and other aquatic organisms, and are most frequently used as references against which the condition of managed streams (e.g., Index of Biotic Integrity) (Karr and Chu 1999) and impacts from management actions can be assessed.

In contrast, there is an emerging paradigm that views streams as being dynamic in space and time, exhibiting a range of potential conditions, as do the terrestrial systems in which they are embedded. The condition of individual streams and watersheds is recognized as variable through time (Naiman et al. 1992) and dependent on landscape context, legacies of past disturbance, and time since past disturbance (Benda et al. 1998, Reeves et al. 1995, Rieman et al. 2006, Wondzell et al. 2007). Larger streams and rivers in the lower portion of the network are less variable through time; those in the upper and middle portions are more dynamic (Naiman et al. 1992). Pristine (i.e., unmanaged) and minimally disturbed aquatic systems may actually exhibit a wider range of conditions than more heavily managed systems (Lisle 2002, Lisle et al. 2007). The range of conditions that aquatic ecosystems in different areas likely experience through time will differ depending on the natural disturbance regime, topographic setting, and geology. See Reeves (2006) for a more detailed review.

Ecological importance of non-fish-bearing streams—
Riparian reserves are a cornerstone of the ACS, and include fish-bearing streams, which had been the focus of the management of aquatic ecosystems before FEMAT, as well as small, fishless headwater streams. Since the ACS was originally developed, the ecological importance of headwater streams, which generally make up 70 percent or more of the stream network (Gomi et al. 2002), has been firmly established. Headwaters are sources of sediment (Benda and Dunne 1997a, 1997b; MacDonald and Coe 2007; Zimmerman and Church 2001) and wood (Bigelow et al. 2007, May and Gresswell 2003, Reeves et al. 2003) for fish-bearing streams, provide habitat for several species of native amphibians (Kelsey and West 1998) and macroinvertebrates (Meyer and Wallace 2001), including recently discovered species (Dieterich and Anderson 2000), and may be important sources of food for fish (Wipfli and Gregovich 2002). Small streams are also storage and processing sites for nutrients and organic matter, forming the energy base for organisms used by fish as food (Kiffney et al. 2000, Wallace et al. 1997, Webster et al. 1999, Wipfli and Gregovich 2002).

Headwater streams are among the most dynamic portions of aquatic ecosystems (Naiman et al. 1992). Tributary junctions between headwater streams and larger channels are important nodes for regulating material flows in a watershed (Benda et al. 2004, Gomi et al. 2002) and are the locations where site-scale effects from management activities are often observed. These locations have unique hydrologic, geomorphic, and biological attributes. The movement of sediment, wood, and other materials through tributary junctions results in sites of high biodiversity (Johnson et al. 1995, Minshall et al. 1985). Habitat in these sites may also range from simple to complex, depending on time since disturbance (such as landslides and debris flows) and the types and amount of materials delivered to the channel.

Wood enters streams via chronic and episodic processes (Bisson et al. 1987). Chronic processes, such as tree mortality and bank undercutting (Bilby and Bisson 1998, Grette 1985, Murphy and Koski 1989), generally introduce single trees or relatively small numbers of trees at frequent intervals. Wood from headwater streams is delivered to fish-bearing streams by large, infrequent events, such as windthrow (Harmon et al. 1986), wildfire (Agee 1993), severe floods, landslides, and debris flows (Benda et al. 2003, Keller and Swanson 1979, May and Gresswell 2003, Reeves et al. 2003). Geomorphic features of a watershed influence the potential contribution of upslope wood sources. Steeper, more highly dissected watersheds will likely have a greater proportion of wood coming from upslope sources than will watersheds with lower stream densities and gradients.

The presence of large wood from headwater streams influences the behavior of landslides and debris flows, and the response of the channel to such events. Large wood in debris flows and landslides influences the run-out length of these disturbance events (Lancaster et al. 2003). Debris flows without large wood move faster and for longer distances than those with wood, and they are less likely to stop high in the stream network. A debris flow without wood is likely to be a concentrated slurry of sediments of various sizes that can move at relatively high speeds over long distances, scouring substrate and wood from the affected channels. These types of debris flows are more likely to negatively affect fish-bearing channels, as compared to the potentially favorable effects that result from the presence of wood. Woodless debris flows can further delay or impede the development of favorable conditions for fish and other aquatic organisms.

Over time, headwater depressions and channels are filled with material from the surrounding hillslopes, including large wood that falls into these channels, forming obstructions behind which sediments accumulate (Benda and Cundy 1990, May and Gresswell 2004). These filled areas are evacuated following a landslide or debris flow. This cycle of filling and emptying results in a punctuated movement of sediment and wood to larger, fish-bearing streams (Benda et al. 1998), which is—at least in part—responsible for the long-term productivity of many aquatic ecosystems (Benda et al. 2003, Hogan et al. 1998, Reeves et al. 1995). The absence of wood to replenish the refilling process may result in a chronic movement of sediment to larger channels, which could lead to those channels developing different characteristics than those that occurred before forest management. Such conditions could be outside the range of watershed conditions to which native biota are adapted (Beschta et al. 2004).

Ecological forestry as a silvicultural guide—
Ecological forestry applies current ecological understanding of forest ecosystems and how they work to achieve integrated environmental, economic, and cultural management outcomes (Franklin and Johnson 2012, Franklin et al. 2007). It contrasts with production forestry, which applies agronomic and economic models in the efficient production of wood products (Franklin and Johnson 2013). Key elements of ecological forestry (Franklin and Johnson 2012, Franklin et al. 2007) include: (1) retaining structural and compositional elements of the pre-harvest stand during variable-retention harvests; (2) using natural stand-development principles and processes to manipulate established stands in order to restore or maintain desired structure and composition; (3) using return intervals for silvicultural activities that are consistent with recovery of desired structures and processes; and (4) planning management activities at landscape scales, in accordance with knowledge of spatial pattern and ecological function in natural landscapes.

Ecological forestry applies current ecological understanding of forest ecosystems and how they work to achieve integrated environmental, economic, and cultural management outcomes.

Franklin and Johnson (2012) distinguish between "moist forests" and "dry forests" (fig. 1) in their recommendations on implementing ecological forestry (box 1), owing to the contrasting disturbance regimes and responses to management of these two types of forests. Historically, moist forests generally experienced large, infrequent wildfires (at intervals of one to several centuries) as their dominant disturbance agent, which produced extensive areas in which fire severity resulted in stand-replacement conditions (Agee 1993). Dry forest sites experienced predominantly low- and mixed-severity fire behaviors at frequent (e.g., 5- to 35-year) intervals (Agee 1993, Perry et al. 2011). Some plant associations currently straddle the boundary between moist and dry forest, but climate change is expected to increasingly shift these associations toward dry forest status, with projected increases in wildfire frequency (e.g., Dello and Mote 2010, Spies et al. 2010).

The distinction between moist forests and dry forests is especially critical in developing policies and practices intended to protect old-growth forests and trees. Existing intact old-growth forests on moist forest sites have undergone limited changes as a result of >100 years of fire exclusion and suppression; active management to restore conditions within such stands is not only unnecessary, but could adversely affect them. Dry forest sites, on the other hand, have undergone dramatic changes from pre-European settlement conditions as a result of many human activities, including the elimination of fire. Consequently, dry forests have undergone significant changes and many are currently dense, fuel-loaded stands dominated by fire- and drought-intolerant species. Hence, policies may permit active management of such forests (including those with older trees) to create more resilient conditions (Franklin and Johnson 2012).

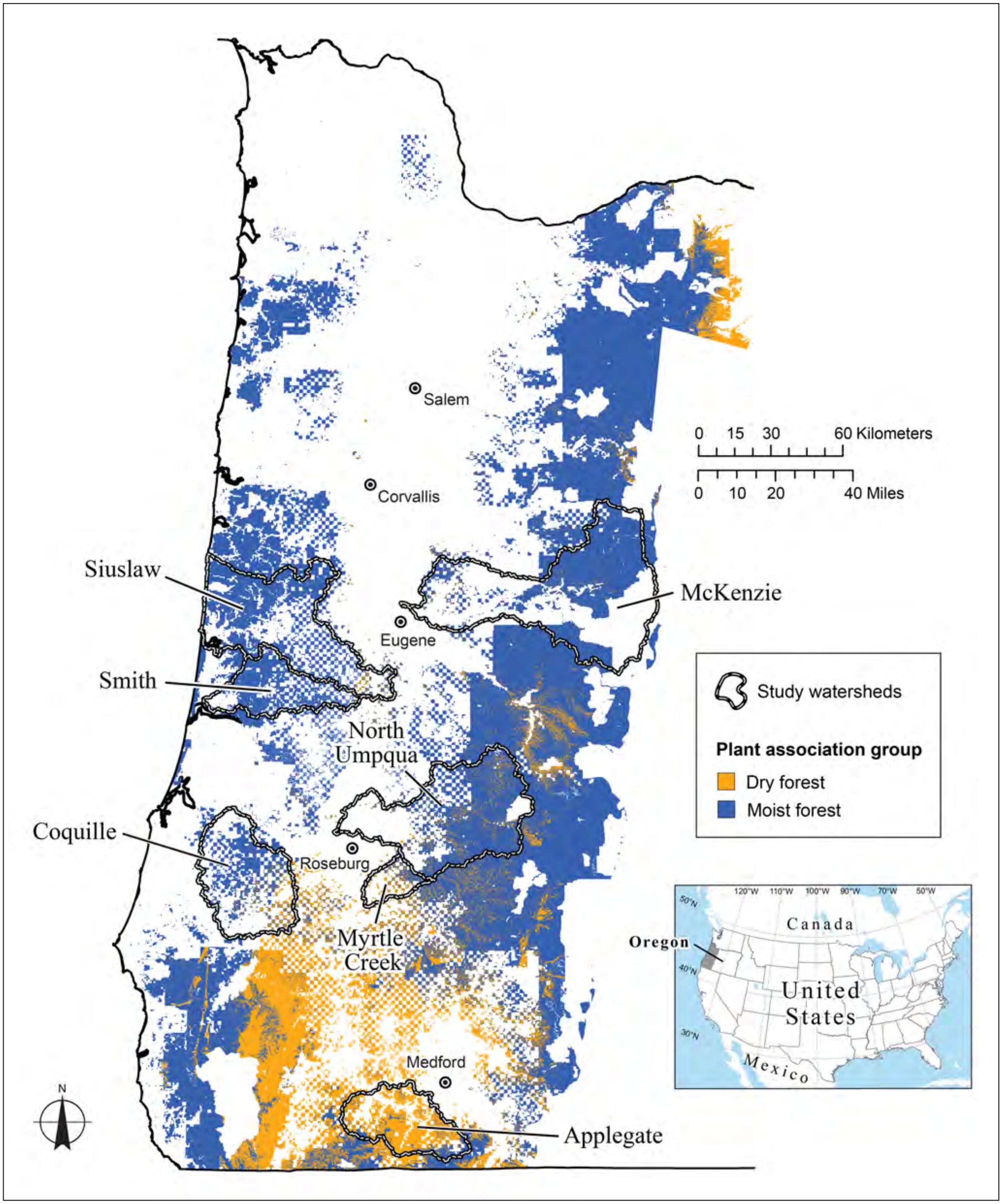

Figure 1—Moist and dry forests (Franklin and Johnson 2012) on Bureau of Land Management and Forest Service lands outside of wilderness in western Oregon, with the six study watersheds highlighted.

Box 1

Elements of Ecological Forestry Strategy (Franklin and Johnson 2012)

Moist forests—

- Retain existing older stands and individual older trees found within younger stands proposed for management, using a selected threshold age.
- Accelerate development of structural complexity in younger stands, using diverse silvicultural approaches (Bailey and Tappeiner 1998, Carey 2003, Garman et al. 2003, Wilson and Puettmann 2007).
- Implement variable-retention harvests (VRH) (Beese et al. 2003; Franklin et al. 1997, 2007; Gustafsson et al. 2012) in younger moist forests, retaining such structures as individual trees, snags, logs, and intact forest patches.
- Accommodate development of diverse early-seral ecosystems following harvest, by using less intense approaches to site preparation and tree regeneration.
- Embed the preceding objectives in a silvicultural system that includes creation and management of multi-aged, mixed-species stands on long rotations (e.g., 100 to 160 years).

Dry forests—

- Retain and improve survivability of older conifers by reducing adjacent fuels and competing vegetation—old trees can respond positively (e.g., McDowell et al. 2003).
- Retain and protect other important structures such as large hardwoods, snags, and logs; some protective cover may be needed for cavity-bearing structures that are currently being used (e.g., North et al. 2009).
- Reduce overall stand densities by thinning so as to: (1) reduce basal areas to desired levels; (2) increase mean stand diameter; (3) shift composition toward fire- and drought-tolerant species; and (4) provide candidates for replacement old trees.
- Restore spatial heterogeneity by varying the treatment of the stand, such as by leaving untreated patches, creating openings, and providing for widely spaced single trees and tree clumps (Larson and Churchill 2012).
- Establish new tree cohorts of shade-intolerant species in openings.
- Treat management-related fuels and begin restoring historical levels of ground fuels and understory vegetation using prescribed fire.
- Plan and implement activities at landscape levels, incorporating spatial hetero-geneity (e.g., provision for denser forest patches) and restoration needs in non-

One specific objective of harvests in moist forests is the creation of diverse early-seral ecosystems as a part of a silvicultural system that includes management of mixed-age, mixed-species forests over long (e.g., 80- to 160-year) rotations. Early-seral ecosystems in moist forests in Oregon are highly diverse, trophic- and function-rich ecosystems that occur after a severe disturbance but before the re-establishment of a closed forest canopy (Swanson et al. 2011). In general, moist forest landscapes are currently lacking in high-quality early-seral ecosystems because of harvest, reforestation, and fire-suppression policies on both private and public lands (Spies et al. 2007, Swanson et al. 2011).

Functional early-seral habitat can be created using variable-retention harvest prescriptions that retain biological legacies and use less-intensive approaches to re-establishment of closed forest canopies (Franklin and Johnson 2012). Unlike conventional clearcuts, these variable-retention harvests retain significant elements of the pre-harvest stand through the following rotation, including undisturbed forest patches and individual live and dead trees that enrich the biodiversity, ecological processes, and structural diversity of the post-harvest stand (Gustafsson et al. 2012, Lindenmayer et al. 2012).

Franklin and Johnson (2012) recommend moist forest variable-retention harvest that retains approximately one-third of the pre-harvest stand, inclusive of riparian buffers for small non-fish-bearing streams embedded in the harvest unit (fig. 2). Most of that retention is in patches, with some additional retention of individual trees scattered over the unit.

With these biological legacies intermixed with openings created by harvest, variable-retention harvests can provide favorable conditions for the development of diverse early-seral ecosystems important for regional biodiversity (Swanson et al. 2011) and the establishment of new cohorts of desirable shade-intolerant tree species, while maintaining a flow of wood products (Franklin and Johnson 2012). Biological legacies, including retained tree patches, individual trees, snags, and down wood, provide structural and biological continuity across successional stages, and lead to multi-story stand structure and heterogeneous landscapes. See figure 3 for an example of diverse early-seral ecosystems following a variable-retention harvest.

The ecological forestry strategy for dry forests (box 1) relies on a combination of stand-level treatments and retention of dense forest habitat patches at the landscape level; such an approach has recently been incorporated into projects on federal lands (e.g., Ager et al. 2007, Franklin et al. 2013, Gaines et al. 2010), and projects using this strategy are underway on BLM lands in southwestern Oregon (Reilly 2012).

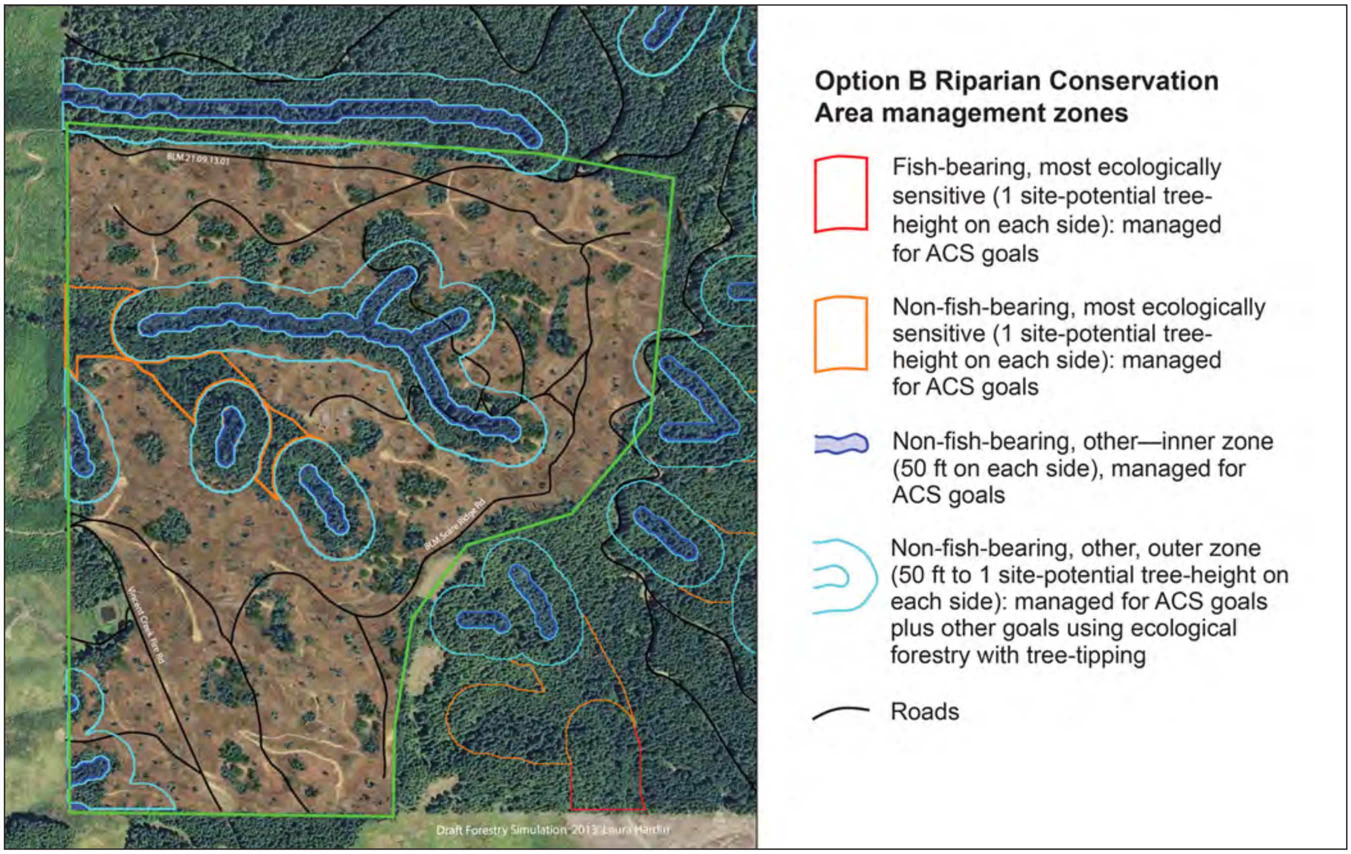

Figure 2—Simulation of Franklin and Johnson's variable-retention harvest scheme with retention patches, scattered retained trees, with retention focused along streams. Retention level across the harvest unit was approximately 35 percent. Simulation by Laura Hardin at the direction of K.N. Johnson, 2013. ACS = Aquatic Conservation Strategy.

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Figure 3—Diverse early-seral ecosystem following a variable-retention harvest.

Retaining and nurturing older trees and other significant structural elements of dry forest stands is the starting point for this restoration strategy. Currently, these older trees and the forests in which they are embedded are at risk from intense wildfires, epidemics of defoliating insects, and competition, the latter resulting in accelerated mortality resulting from bark beetles (Franklin and Johnson 2012). The dry forest restoration strategy is designed to reduce these risks.

We focus the discussion of ecological forestry in this report on moist forests because they cover most of our study watersheds, and involve the most controversial harvest practice—variable-retention harvest to create openings. To achieve the goals of the ACS, activities in moist forests within riparian conservation areas (the area of interest for aquatic conservation) should generally be limited to stands currently less than or equal to 80 years of age.[1] Watersheds with forests 80 to 140 years old in the Oregon Coast Range are believed to be the most productive for salmon (Reeves et al. 1995). For example, reaches of streams with natural forests greater than 80 years old had the highest abundances of juvenile Chinook salmon (*O. tshawytscha*) in Elk River, Oregon (Burnett 2001). The joint riparian review group from the National Marine Fisheries Service, U.S. Forest Service, BLM, Environmental Protection Agency, U.S. Geological Survey, and U.S. Fish and Wildlife Service recommended that thinning be limited to stands less than or equal to 80 years of age (Spies et al. 2013). Also, Franklin and Johnson (2012) view younger, previously harvested acres (generally stands currently less than or equal to 80 years of age) as prime candidates for variable-retention harvests, given that the area of older forests is far below historical levels (FEMAT 1993) and that scientific review (Forsman et al. 2011) and policy direction (USFWS 2011, 2012) increasingly call for retention of mature and old forest in matrix as northern spotted owl habitat. The silvicultural practices of ecological forestry for moist forests differ between the inner and outer zones of the riparian conservation area in the options evaluated here. The inner zone is managed solely to achieve the goals of the ACS; thinning could be allowed to further ACS goals. The outer zone is managed to achieve the goals of the ACS and for other goals, including timber production using ecological forestry. Both thinning and variable-retention harvest could be allowed in the outer zone.

[1] Most stands currently less than 80 years of age were previously clearcut and planted; many have since been precommercially thinned and some have been commercially thinned. Note that not all stands currently ≤80 years of age would be available. Some include a remnant overstory of older trees that could make them function as older stands from a biodiversity standpoint; their availability for long-term timber production may be limited under the guidance in the Northern Spotted Owl Recovery Plan (USFWS 2011) and the guidance in the Northwest Forest Plan for conservation of marbled murrelet sites as they are found (USDA and USDI 1994).

Tree-tipping to compensate for potential reduction in wood recruitment—The lack of wood in streams in managed forests is a primary concern of management and regulatory agencies, and warrants consideration in any riparian management scheme. Thinning is a potential technique for increasing tree growth (Dodson et al. 2012, Garman et al. 2003), and the purposeful placement of some proportion of the harvested wood in the channel or on the forest floor could immediately reduce deficiencies in dead wood that exist in many streams and riparian areas (Benda et al. 2015; see also Olson and Burnett 2009 and Olson and Kluber 2014). Thinning would produce more dead wood in riparian areas and streams in the short term than a stand that is left unthinned, where dead trees accumulate slowly as a result of competition, disease, disturbance, and other factors. Given the right stand conditions, such actions could have the added benefit of accelerating future development of very large-diameter (>40 inches) trees (Spies et al. 2013). However, any thinning activity to increase wood recruitment in the near and long terms will also have to consider potential impacts on water temperature and water quality.

Benda et al. (2015) explored tree-tipping by modeling the amount of instream wood that would result from thinning a stand from 400 trees per acre to 90 trees per acre, which is considered a moderate amount of thinning, then directionally falling or pulling over varying proportions of the trees scheduled for harvest (table 1). This was compared to the amount of wood that would be expected to be found in the stream without thinning the stand. The amount of wood increased above the "no thin" level immediately after the entry in all of the options of wood additions. However, the cumulative total amount of wood expected in the stream over 100 years relative to the unthinned stand varied depending on the amount of wood delivered. Adding ≤10 percent of the wood that would be removed during thinning produced less wood in the channel over time than the unthinned option. When 15 to 20 percent of the volume of thinned trees was tipped from one side of the stream at each entry, the total amount of dead wood in the channel over time exceeded the unthinned scenario (table 1).

While further modeling is being done to better understand the effects of tree-tipping, the initial modeling results and other published papers (Carah et al. 2014, Spies et al. 2013) suggest that adding wood to streams during management activities could provide benefits to fish and fish habitat. We therefore include tree-tipping in the two management options described below. We assume that this topic will be further explored and evaluated through time, and that appropriate modifications of its application could be made as new knowledge is generated.

Adding wood to streams during management activities could provide benefits to fish and fish habitat.

Table 1—Predicted cumulative wood storage ($m^3 \cdot 100\ m^{-1}$) over the simulated century (includes decay), showing differences between the no-treatment alternative in comparison to various combinations of single- and double-entry thins, a 10-m buffer, and tree-tipping of between 5 percent and 20 percent

	Change from no treatment	
Scenario	Single-entry thin	Double-entry thin
	Percent	
No treatment (reference)	0	0
Thin	-33	-42
Thin, buffer	-7	-11
Thin, tip 5 percent	-15	-15
Thin, tip 10 percent	-6	+1
Thin, tip 15 percent	+1	+16
Thin, tip 20 percent	+6	+24

Potential Options for Managing Riparian Reserves on BLM Western Oregon Forests—Design and Scientific Rationale

Based on recent scientific information, we design and compare two potential options for managing the interim riparian reserve on BLM lands in western Oregon (fig. 4) that meet ACS objectives and concerns related to ESA-listed fish (fig. 5), while also meeting other management objectives. In both options, the interim riparian reserves are retained in late-successional reserves (fig. 6), which were primarily areas with mature and old-growth forests and key habitats for the northern spotted owl and the marbled murrelet (*Brachyramphus marmoratus*) (Thomas et al. 2007), and in other reserves. Both options focus on the area within one site-potential tree-height of fish-bearing and non-fish-bearing streams, which we call the riparian conservation area. On matrix lands, where timber production with thinning and regeneration harvest is one of the goals (USDA and USDI 1994), and in adaptive management areas, where innovative adaptive management practices were to be tried, the riparian conservation area of one tree-height is divided into an inner zone and outer zone. The inner zone is solely devoted to achieving goals of the ACS; the outer zone is managed to achieve ACS goals as well as other potential goals, which could include timber production, achieved through ecological forestry practices. One option uses a fixed-width approach to divide the riparian conservation area between the two zones; the other uses a context-dependent approach based on the ecological characteristics of the stream reach. “Tree-tipping” is used throughout

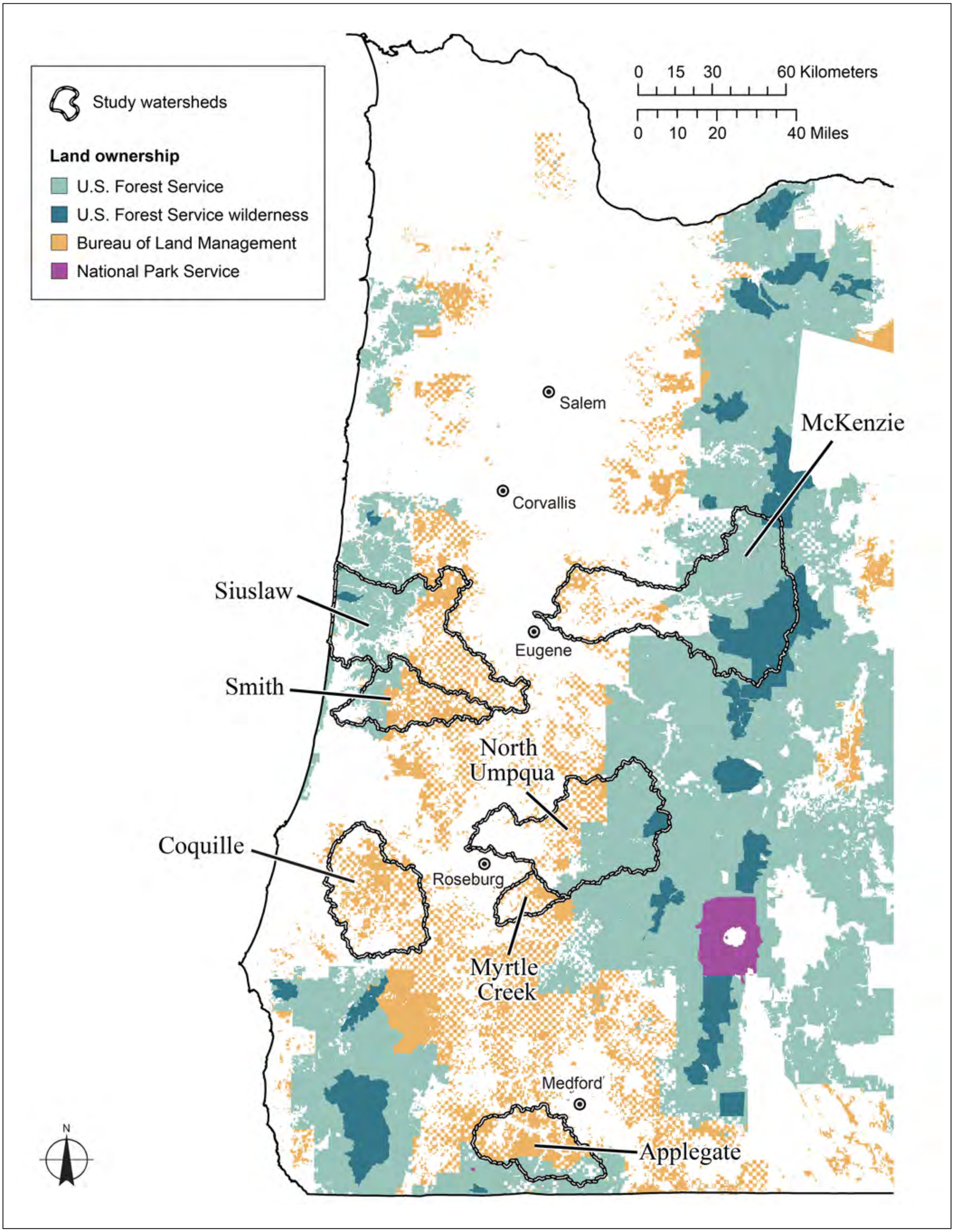


Figure 4—Land ownership in western Oregon, with the six study watersheds highlighted.

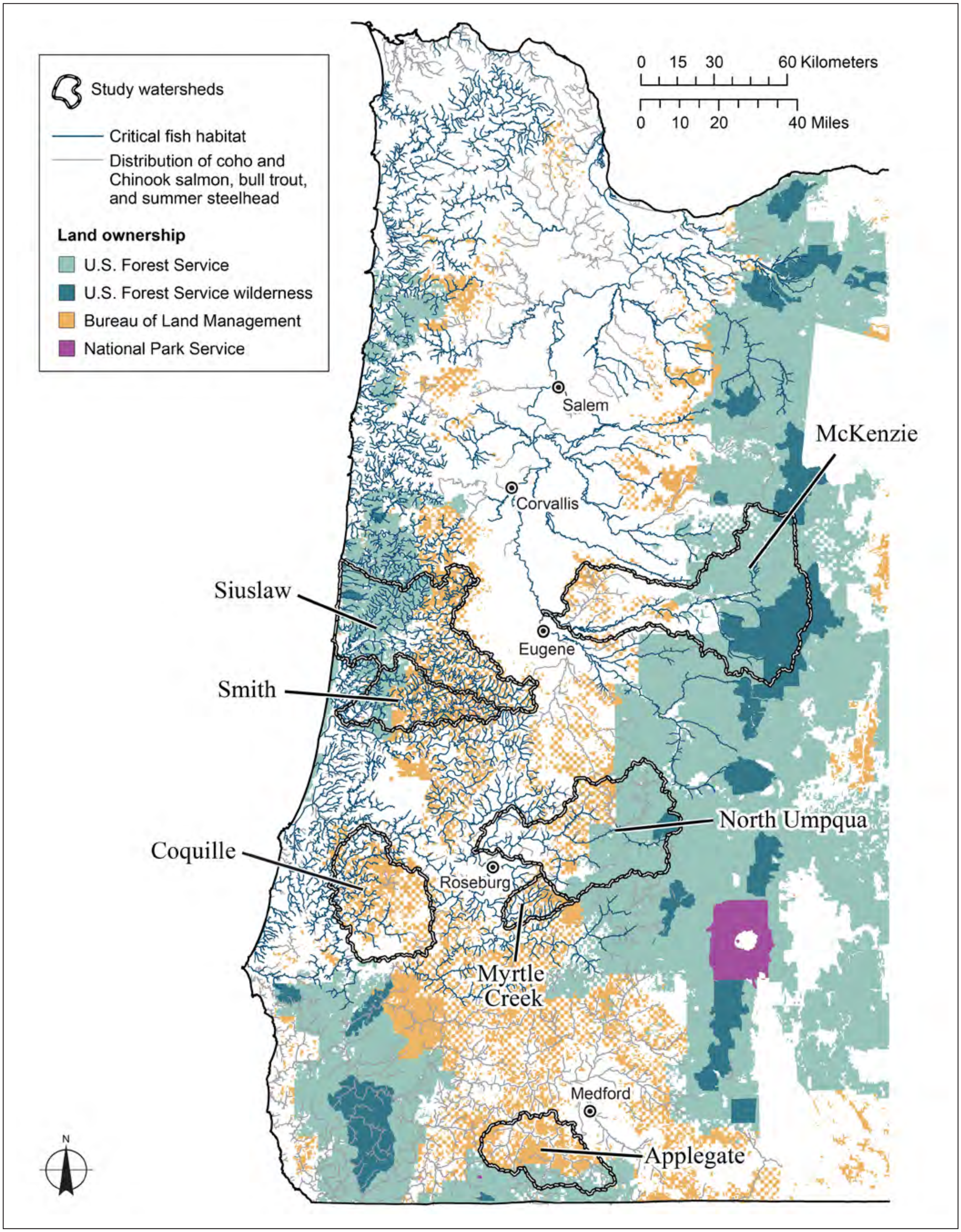


Figure 5—Critical habitat for the Oregon Coast coho salmon, and Willamette River bull trout, spring Chinook salmon, and summer steelhead evolutionarily significant units (ESUs), with the six study watersheds highlighted. Critical habitat for the Southern Oregon/ Northern California ESU for coho salmon is not shown because spatial data were not available.

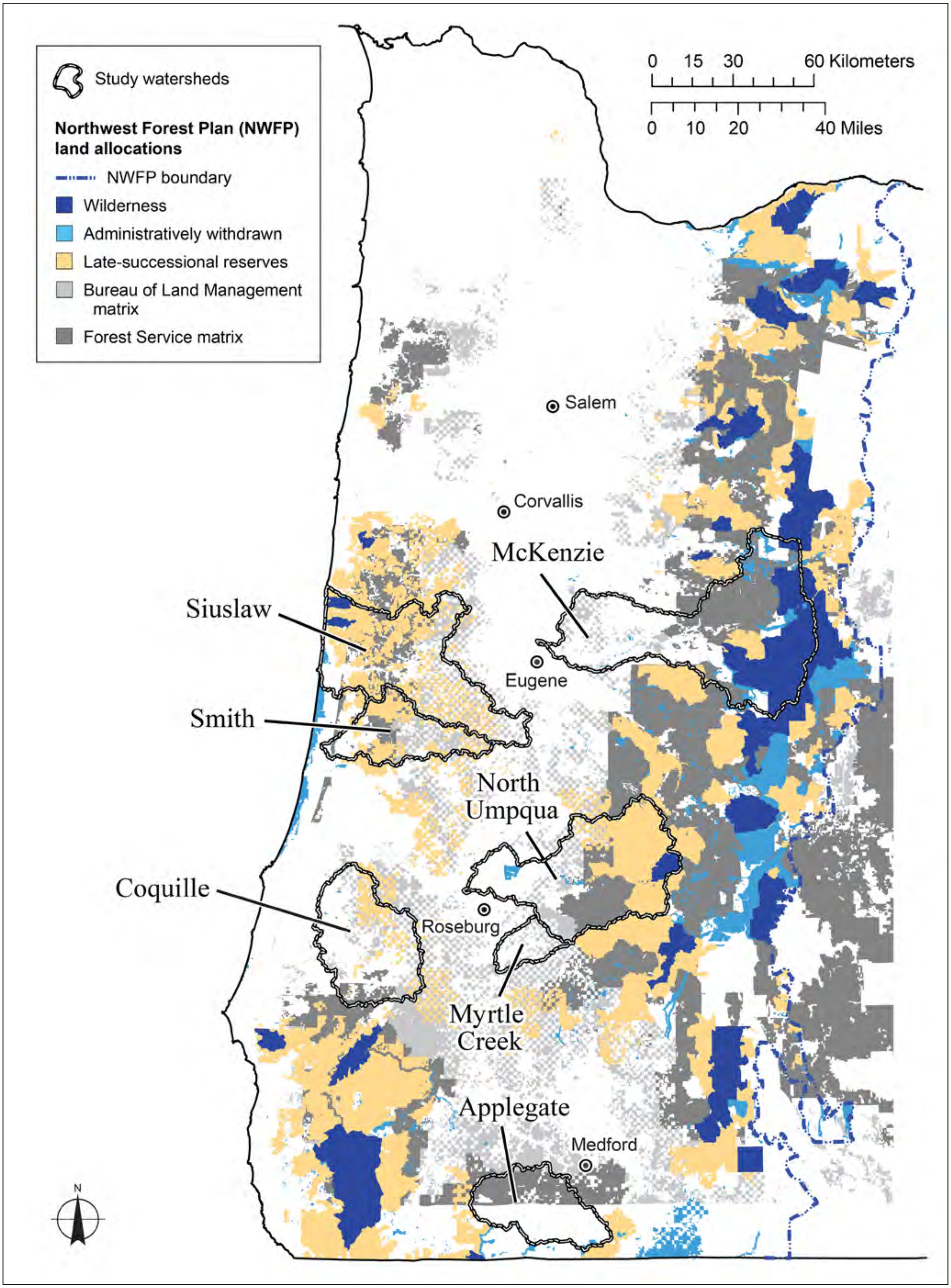


Figure 6— Northwest Forest Plan land allocations for western Oregon, with the six study watersheds highlighted.

the riparian conservation area to ensure that any harvest does not negatively affect wood recruitment to the stream. Both options limit harvest within one site-potential tree-height of streams to stands currently less than or equal to 80 years in age. Also, the recently developed recovery plan for the northern spotted owl and associated critical habitat (USFWS 2011) (fig. 7) will further limit harvest of mature and old-growth forest within two site-potential tree-heights of streams and throughout the matrix.

We first discuss the logic behind the potential options and then simulate the application of these two options for BLM matrix in six watersheds, along with the interim riparian reserves for comparison.

Option A

Under option A, all the components of the ACS are applied. Interim riparian reserves are retained in the late-successional reserves and other special land designations. In matrix, a riparian conservation area of one site-potential tree-height is recognized along all streams. For fish-bearing streams in matrix, the riparian conservation area would be managed solely to achieve goals of the ACS, as would an inner zone of one-half site-potential tree-height on non-fish-bearing streams (fig. 8). An outer zone of the riparian conservation area on non-fish-bearing streams equal to the remaining one-half of a site-potential tree-height could include timber production as an additional goal (see box 1 for prescriptions that could be considered in the outer zone).

Options A and B retain all components of the Aquatic Conservation Strategy.

Scientific considerations for riparian conservation areas along fish-bearing streams—
A primary purpose of the riparian conservation areas is to maintain the key ecological processes that contribute to the long-term productivity of the aquatic ecosystem, similar to the purpose of the interim riparian reserves of the ACS. These processes occur almost exclusively within the first site-potential tree-height from the stream (USDA and USDI 1994), and include the beneficial effects of root strength for bank stability, litter fall, shading to moderate water temperatures, and delivery of coarse wood to streams (fig. 9a). In addition, the majority of moderating effects of sediment delivery to streams from overland erosion associated with upland activities generally occurs within a distance of one site-potential tree-height (Castelle et al. 1994, Naylor et al. 2012).

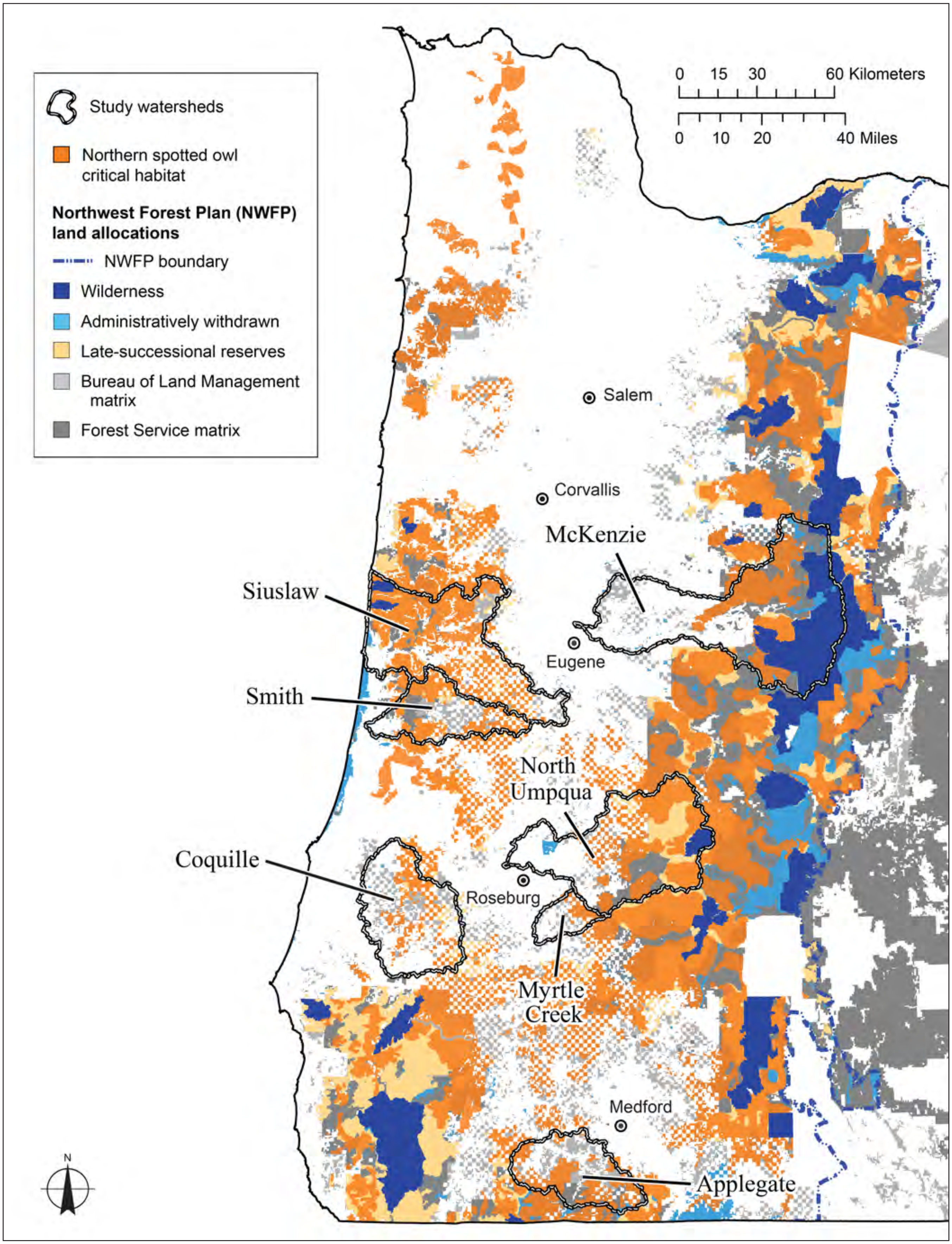


Figure 7—Northern spotted owl critical habitat for Oregon, over Northwest Forest Plan land allocations, with the six study watersheds highlighted.

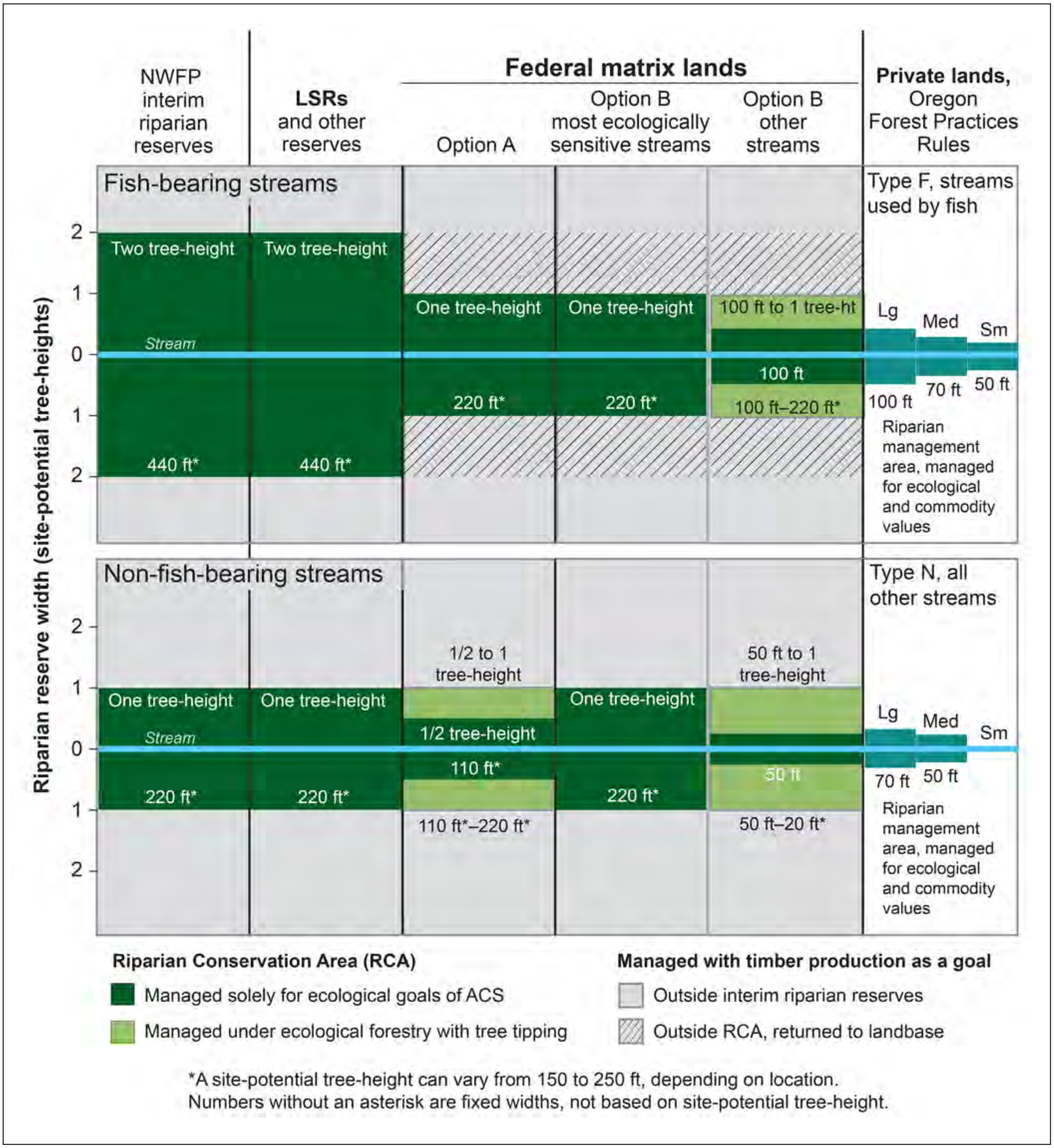


Figure 8—Comparison of the widths of riparian reserves under current federal policy, the inner and outer zones of riparian conservation areas under potential options A and B, with riparian management areas as they apply to private lands under the Oregon Forest Practices Rules as contrast.

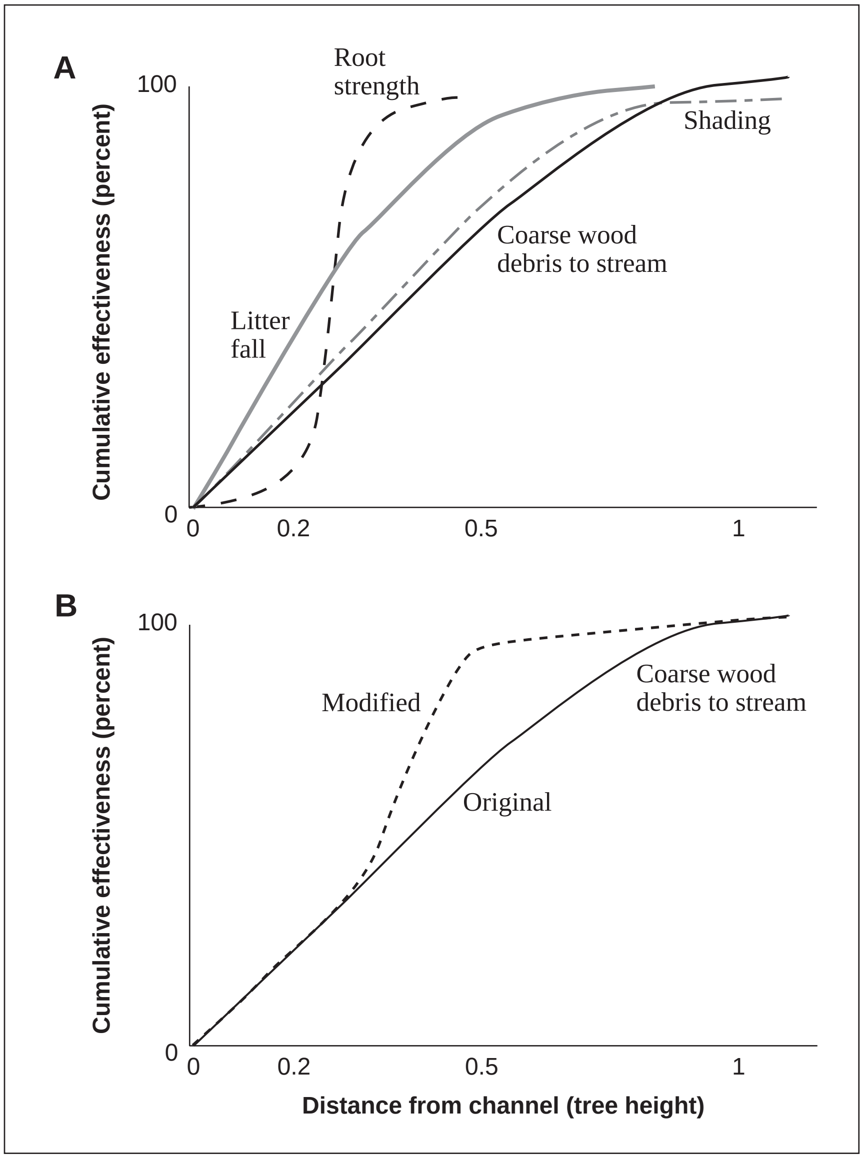


Figure 9—(A) Relation of distance from stream channel to cumulative effectiveness of riparian ecological functions. From: FEMAT (1993, p. V-27); (B) Modified effectiveness curve for wood delivery to streams as a function of distance from the stream channel. The curve was changed based on scientific literature developed since the original curve was portrayed in FEMAT (1993).

One site-potential tree-height from the edge of a stream may not encompass the entire floodplain of some fish-bearing streams. Forests in floodplains can be important sources of large wood that provide a suite of ecological functions (Latterell and Naiman 2007). In such cases, it is critical to recognize and protect the entire floodplain. This was accomplished in the ACS by requiring the boundary of the riparian reserve to extend to the edge of the 100-year floodplain (USDA and USDI 1994). That requirement would be retained under options A and B. In any case, most fish-bearing streams on BLM lands in western Oregon are small to medium in size, without extensive floodplains. As a result, one site-potential tree-height should be sufficient to retain the full suite of ecological processes in most situations.

A primary purpose for the extension of the boundary of the riparian reserve of the Northwest Forest Plan from one site-potential tree-height to two on fish-bearing streams was to protect and enhance the microclimate of the riparian ecosystem within the first tree-height (USDA and USDI 1994). Research on the effects of clearcutting on microclimatic conditions in adjacent upland forest stands (Chen et al. 1993) found that the influence (of the clearcut) extended from yards (e.g., soil moisture) to hundreds of yards (e.g., wind velocity) into adjacent unharvested stands. Based on the initial work of Chen et al. (1993), FEMAT (1993) hypothesized that a second tree-height could provide significant benefits to riparian reserves in terms of relative humidity and other microclimatic effects in the riparian reserve along fish-bearing streams (FEMAT 1993, fig. V-13, p. V-27).

In the years since the ACS and associated ecological function curves were originally formulated, a number of research efforts have examined the effects of forest management on microclimate in riparian areas. The vast majority of this work has focused on small, headwater streams; few studies were conducted along larger streams (see review by Moore et al. 2005; Olson et al. 2007, 2014). The magnitude of harvest-related changes in microclimate in riparian areas is usually inversely related to the width of the riparian buffer and the type and extent of management activities on the outer edge. The extent varied from a distance of 30 m (Anderson et al. 2007, Rykken et al. 2007) to 45 m (Brosofske et al. 1997) from the stream. A microclimate "stream effect" counteracts harvest edge effects, reducing the distance of climate effects in riparian zones (Rykken et al. 2007) from those projected by Chen et al. (1993) in uplands. Hence, the FEMAT microclimate curves are not necessarily accurate for riparian areas with a strong stream effect. As a result, a one tree-height buffer on fish-bearing streams has been suggested as a means to substantially reduce potential impacts of harvesting in areas on the edge of the riparian reserve on riparian microclimate and water temperature (Brosofske et al. 1997, Moore et al. 2005).

A one tree-height buffer on fish-bearing streams reduces potential impacts of harvesting in areas on the edge of the riparian reserve on riparian microclimate and water temperature.

Uncertainties exist in reducing the size of the Northwest Forest Plan's riparian reserves. One concern is the potential for increased warming of streams. The scientific evidence is mixed on this issue (see review by Moore et al. 2005); generally, the smaller the riparian area and the more extensive the activities, the greater the effect on stream temperature. Pollock et al. (2009) examined water temperatures in watersheds with varying extent of timber harvest. They found that watersheds with no harvest had statistically lower water temperatures than those with varying amounts (12.1 °C vs. 14.5 °C). Although the differences are statistically significant, the ecological consequences are less clear. The higher temperatures are still well within the range considered suitable for native fish (not mentioned by the authors) and below state standards in Oregon (ODEQ 2015). Additionally, Pollack et al. (2009) found that the amount of recently clearcut riparian forest (<20 years) within 600 m upstream of their monitoring sites ranged from 0 to 100 percent and was not correlated with increased stream temperatures. However, the options we evaluated do not allow clearcutting in riparian areas.

Other factors such as substrate (Janisch et al. 2012, Johnson 2004) and topographic shading can influence water temperatures as much as, and perhaps more than, shade from streamside forests. Although there is a potential for streams to warm as a result of silvicultural activities, the likelihood is very small when harvest takes place beyond one tree-height. This is especially applicable to small streams because temperature increases in headwater streams are unlikely to produce substantial changes in the temperatures of larger streams into which they flow, unless the total inflow of heated tributaries constitutes a significant proportion of the total flow in the receiving stream (Kibler et al. 2013, Moore et al. 2005).

Scientific considerations for riparian conservation areas along non-fish-bearing streams—

Effect on microclimate and water temperature—Anderson et al. (2007) conducted one of the more comprehensive studies on the effect of vegetation manipulation in riparian areas of varying sizes, in stands 30 to 70 years old. They monitored microclimatic conditions in riparian areas on fish- and non-fish-bearing headwater streams in western Oregon that had varying widths (<49 to 492 ft [14.9 to 150 m]) and moderate levels of thinning (reducing trees from 250–432 trees per acre to 100 trees per acre), and measured changes in microclimate above the stream channel and in the adjacent riparian zone, relative to unthinned stands. With riparian management areas of 49 ft or greater width, daily maximum air temperature above the stream center was less than 1°C higher, and daily minimum relative humidity was less than 5 percent lower than for unthinned stands. If the area adjacent is clearcut, a 98.5-ft (30-m) riparian management area maintains microclimatic conditions (Rykken et al. 2007).

Under option A, the inner zone of the resource conservation area along non-fish-bearing streams managed solely to achieve the goals of the ACS equals one-half the height of a site-potential tree (minimum distance of 75 ft [22.9 m]). This width is greater than the 49-ft (15.9-m) threshold width reported by Anderson et al. (2007); at greater widths, post-treatment air temperature and humidity at stream center increased less than 1 °C and 5 percent, respectively. Strategic placement of aggregate or dispersed retention during variable-retention harvest (recommended as one-third of the preharvest stand) should help ameliorate potential negative impacts. As an example, retaining trees along the half-tree-height boundary would increase the effective width of the inner zone. Also, reduction in tree density in the outer zone could provide benefits, in the form of increased growth of trees, to trees in the inner zone, up to 49 ft (15 m) into an unthinned stand from the edge of a thinned stand (Ruzicka et al. 2014). Thus, although the area devoted solely to achieving the goals of the ACS is smaller than that of the interim riparian reserves, there is evidence to suggest that the suite of ecological benefits should be retained as part of a comprehensive approach that includes ecological forestry and tree-tipping (fig. 10).

Relative to temperature effects, non-fish-bearing streams tend to be narrow channels in steeper constrained valleys (Gomi et al. 2002, Moore et al. 2005). Near-stream vegetation and topographic features often shade the entire channel in such settings (Janisch et al. 2012), thus the application of the curve for shade in the FEMAT ecological curves graph (fig. 9a) is not necessarily appropriate. In addition, water temperatures in headwater streams are strongly influenced by in-channel substrate (Janisch et al. 2012, Johnson 2004). Neither of these factors would be affected by narrowing the riparian management areas, and adopting option A for non-fish-bearing streams is not anticipated to increase water temperatures in these streams.

Effect on amphibians—Olson et al. (2007) reviewed studies of the effects of timber harvest activities, inside and outside of riparian reserves, on microclimatic conditions and amphibians. They concluded that relatively narrow buffers (compared to those of the Northwest Forest Plan) can be effective in maintaining microclimates 33 to 66 ft (10 to 20 m) from the stream center, although the type of upland harvest matters (Rykken et al. 2007). Potential concerns about microclimate can be further reduced by minimizing clearcutting along the outer boundary of riparian management areas (Anderson et al. 2007, Kluber et al. 2008, Moore et al. 2005). As mentioned previously, clearcutting is not part of the silvicultural strategy under ecological forestry; strategically placing aggregated retention patches during harvest should help allay concerns. Instream and streambank amphibians were retained with a 49-ft (15-m) riparian management area through two rounds of upslope harvest in headwater streams in the Coast and Cascade ranges of western Oregon (Olson and Burton 2014). Management of the one-half of a site-potential tree-height (minimum distance of 75 ft [22.9 m]) along each side of non-fish-bearing streams (the inner zone) solely for ACS goals, and using ecological forestry and tree-tipping

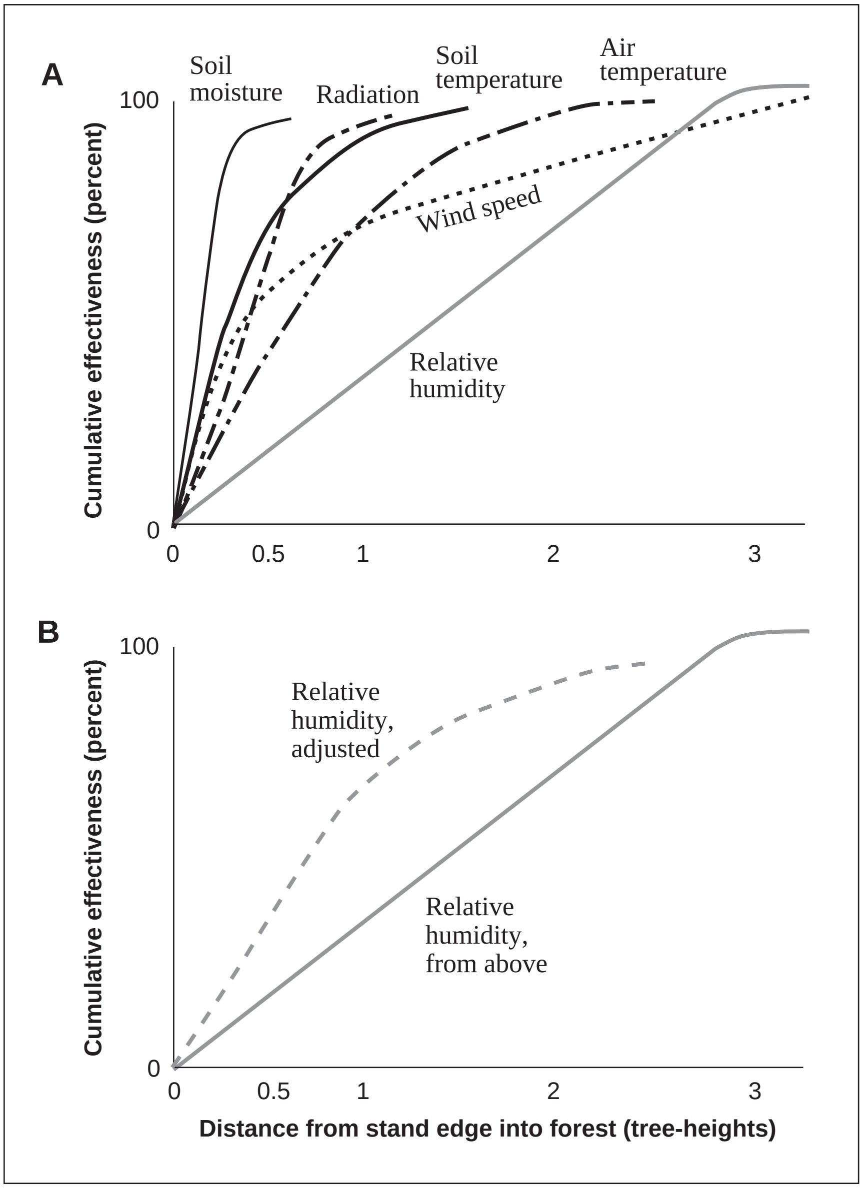


Figure 10—(A) Relation of distance from stream channel to cumulative effectiveness of factors influencing microclimate in riparian ecosystems. From FEMAT (1993, p. V-27); (B) Modified effectiveness curve for relative humidity as a function of distance from the stream channel. The curve was changed based on scientific literature developed since the original curve was portrayed in FEMAT (1993).

on the distance equal to the other half of a site-potential tree-height (the outer zone) should be sufficient to maintain favorable conditions for many amphibians (Olson and Burton 2014).

Headwater streams may also serve as connection corridors within and between watersheds (Olson and Burnett 2009). Most amphibians moved along the stream within 45 ft (13.6 m) of the channel (Olson and Kluber 2014). Maintaining a one tree-height riparian conservation area on non-fish-bearing streams, with the inner half (at least 75 ft [22.9 m] in width) solely devoted to the ACS goals of the NWFP and the outer half managed with ecological forestry, should provide movement corridors for amphibians and other organisms within and between watersheds. Retention of the interim riparian reserves in late-successional reserves and other areas also provides movement corridors. In addition, providing for down wood on the forest floor during harvest, by tree-tipping, will further reduce potential impacts on terrestrial salamanders (Olson and Kluber 2014, Rundio and Olson 2007).

Allowing ecological forestry in the outer zone of riparian conservation areas along non-fish-bearing streams with tree-tipping is unlikely to adversely affect wood recruitment.

Effect on wood recruitment—Allowing ecological forestry in the outer zone of riparian conservation areas along non-fish-bearing streams with the requirement for tree-tipping is also unlikely to adversely affect wood recruitment. The graph of the relationship between the cumulative effectiveness of an ecological process and the distance (expressed as the height of a site-potential tree) for wood recruitment from the immediately adjacent riparian area, developed in FEMAT (1993), suggested that about 60 percent of wood recruitment function occurs within one-half of a tree-height (fig. 9a). This graph was based on a limited number of studies (McDade et al. 1990, Van Sickle and Gregory 1990) and the professional judgment of scientists involved with FEMAT. Since publication of the FEMAT (1993) report, new examinations of studies on the sources of wood (Spies et al. 2013) and information in Gregory et al. (2003) suggest that, in the Cascade Range of western Oregon, about 95 percent of the total instream wood inputs from the adjacent riparian area came from distances that ranged between 82 to 148 ft (25 to 45 m) from the stream. Given that the height of a site-potential tree in the study area is approximately 180 ft,[2] this suggests that 95 percent of the wood comes from a distance equal to 0.46 to 0.82 of a site-potential tree-height (fig. 9b). This scientific finding compares to the hypotheses expressed in the FEMAT curve (fig. 9a), showing that 95 percent of the wood recruitment function occurs within a distance equal to about 0.95 of the height of a site-potential tree. Thus, more of the wood recruitment comes from the inner half of a site-potential tree-height than assumed in FEMAT; managing this inner half solely for the goals of the ACS and managing the outer half of the riparian conservation area using ecological forestry and requiring tree-tipping should maintain the wood recruitment process in non-fish-bearing streams.

Initial analyses (Benda et al. 2015) suggest that placing 15 to 20 percent of the total volume that would be harvested in the inner zone (thinning) and the outer zone (thinning and variable-retention harvest) in the channel would result in as much

[2] Personal communication. Cheryl Friesen, science liaison, Willamette National Forest, 57600 McKenzie Highway, McKenzie Bridge, OR 97413.

wood in the channel as would accumulate in unharvested stands (table 1). This amount is likely to be sufficient in most cases, but site-specific analyses can be used to estimate the amount needed for a given setting. Implementing directional felling and placement of wood in the channel can present operational challenges. Methods and procedures need to be developed to ensure that this can be done successfully so that the goal for wood loading is met.

Option B

Option B is based on the same scientific findings discussed for option A. However, rather than taking a "one-size-fits-all approach," this potential option employs a context-dependent approach that recognizes natural variation in where ecological processes critical to aquatic habitats occur within a watershed, and the inherent capacity of streams to provide habitat for selected fish species. This concept was not well understood or recognized at the time of the development of the ACS in the NWFP.

Option B employs a context-dependent approach.

Rationale and concepts for a context-dependent approach to riparian conservation and management—
Management of riparian areas has almost exclusively used fixed-width buffers, with the prescribed width determined by the stream size (average flow) or type (presence or absence of fish) (Richardson et al. 2012). This approach is easy to administer and apply, and is less costly than developing site-specific recommendations, in part because of the analysis required for the latter approach. The combination of these factors and uncertainty about results has limited the development and application of a context-dependent approach to riparian management.

A key component of the ACS is watershed analysis (FEMAT 1993), which is supposed to provide the context of a given location for adjusting the boundaries of, and allowing activities within, riparian reserves. However, the original intent of watershed analysis was never realized (Reeves et al. 2006), owing to a number of factors, including cost of analysis and the need to consider a multitude of species and their ecological requirements (USDA and USDI 1994). Neither FEMAT (1993) nor the Record of Decision (ROD) (USDA and USDI 1994) provided explicit criteria for changing the boundaries or demonstrating that proposed changes would meet or not prevent attainment of ACS objectives over the long term. Finally, there was also a lack of credible analytical tools to aid decisionmaking (Reeves 2006). As a result, adjustments proved difficult for the agencies to make, and interim boundaries of the riparian reserves remained intact in the vast majority of watersheds (Baker et al. 2006).

There has been a call in the scientific literature to allow discretion in setting site-specific activities (Lee et al. 2004). This flexibility is directed toward the management of riparian areas, and depends on the "context" of (Kondolf et al. 2003, Montgomery 2004) and primary management objective for the specific area (Burnett and Miller 2007). A mix of approaches could be undertaken that recognize ecological and other goals, such as timber harvest, especially if applied over larger spatial scales (Burnett and Miller 2007) and if consideration is given to the distribution of populations of concern and connectivity among them (Olson et al. 2007, 2014). However, management options (Naiman et al. 2012), and many restoration efforts (Kondolf et al. 2003), are constrained by a reliance on "off-the-shelf" and one-size-fits-all concepts and designs, rather than on an understanding of specific features and capabilities of the location of interest.

There have been few attempts to design and implement a site-specific approach because available guidelines are vague (Naylor et al. 2012, Richardson et al. 2012). The best example is the Cissell et al. (1998, 1999) proposal for the Central Cascades Adaptive Management Area. Developed by many of the scientists involved in creation of the Northwest Forest Plan, the proposal was based on variation in the disturbance patterns (in this case, wildfire) in the target watershed, and called for harvest of some older trees and revision of the interim riparian reserves. Only limited parts of the proposal were ever implemented, however, and adjustments to riparian reserves were not made, in large part to avoid controversy and protest over the harvest of mature stands.

Under the context-dependent approach that we use for this potential option, the division of the riparian conservation area between the inner and outer zone could be tailored to the specific features and characteristics of individual stream reaches. Factors considered are: (1) the potential of streams and stream reaches to provide habitat for different fish species (Burnett et al. 2007); (2) the potential for erosion of stream-adjacent areas; (3) the potential of a stream to warm if streamside vegetation is modified; and (4) the potential of headwater streams to deliver wood to fish-bearing streams.

Implementing a context-dependent approach—
In option B, the division of the riparian management area between the inner and outer zones depends on the ecological context of the area. Site features include intrinsic potential (Burnett et al. 2007) for coho salmon and steelhead, thermal loading potential and erosion potential for fish-bearing streams, and potential of non-fish-bearing streams to deliver wood to the locations of interest. To map and analyze site features in our study watersheds, we employed NetMap (Benda et al.

2007), a geospatial platform that integrates a suite of models and analysis tools to provide insights about the landscape context of locations in a timely and cost-effective manner, as watershed analysis was originally intended to do. NetMap uses models that are available in the published scientific literature to identify selected watershed features, such as channel gradient, valley configuration, channel orientation, and landslide susceptibility, which can be used to establish the context of a location of interest. We used NetMap to identify and help evaluate these key site features:

Intrinsic potential of fish-bearing streams—
Intrinsic potential (IP) (Burnett et al. 2007) is an estimate of the capability of a given stream or stream segment to provide suitable habitat for a given species (table 2). We used IP to assess the potential of reaches in fish-bearing streams to provide productive habitat for coho salmon and steelhead, and considered stream reaches with IP > 0.5 as the "most ecologically sensitive." Generally, an IP value of 0.5 to 0.7 represents a moderate capacity for production, and an IP > 0.7 is considered a high capacity (Burnett et al. 2007). Because of the heightened concern about fish and fish habitat on BLM and other lands, we recognize stream reaches with either high or moderate IP values as "most ecologically sensitive" to minimize potential adverse consequences.

Table 2—Parameters considered in assessing intrinsic potential (IP) (Burnett et al. 2007) for various fish species

Species	Stream size (mean annual flow)	Gradient	Ratio of valley width/active channel width
	$m^3 \cdot s^{-1}$	*Percent*	
Coho salmon (*Oncorhynchus kisutch*)	0.5–30	<1	8–10
Steelhead (anadromous *O. mykiss*)	0.5–75	2–5	1–5

Thermal loading potential of fish-bearing streams—
This variable was used as the best proxy to represent stream temperatures at the watershed scale. The susceptibility of a stream reach to warming is strongly influenced by topography and stream orientation, as well as riparian vegetation (Beschta et al. 1987, Sinokrot and Stefan 1993, Webb and Zhang 1997). Parameters used in the NetMap model of thermal loading for determining direct beam and diffuse solar radiation include: (1) topographic shading, (2) channel width, (3) aspect, (4) latitude, and (5) height and density of streamside vegetation. In concert with NetMap's solar radiation model, incoming diffuse, direct, and total radiation for every vertex in a

stream network was calculated based on hourly intervals on July 20th, on average the warmest day of the year. Thermal load to a stream reach (watt-hours · m^{-2}) was calculated as the hourly average of all vertices of the reach, summed over all daylight hours. To evaluate the effect of harvest within the outer zone of the riparian conservation area on thermal loading at the stream, we modeled two management scenarios on each fish-bearing stream reach of the subject watersheds. The first modeled scenario represented an undisturbed buffer of one tree-height on each side of the stream, and the second scenario represented a contracted buffer of 100 ft (30.5 m) on each side of the stream. Modeled vegetation conditions were 70-percent vegetation density and full tree-heights inside the buffers, and clearcut harvest outside of the buffers. The percent increase in thermal loading of the contracted-buffer model with respect to the thermal loading of the full-buffer model was calculated for each stream reach. Stream reaches with greater than 10 percent increase in thermal loading were assigned to the "most ecologically sensitive" category of our analysis (table 3).

Table 3—Parameters used to determine riparian management classes of different stream types

Management category	Stream type	Site criteria
Most ecologically sensitive	Fish-bearing	Intrinsic potential > 0.5 for any species OR Changes in thermal loading > 10 percent OR High erosion potential
	Non-fish-bearing	High probability of delivering sediment and wood to a fish-bearing stream
Other	Fish-bearing	All other fish-bearing streams
	Non-fish-bearing	All other non-fish-bearing streams

Erosion potential of fish-bearing streams and debris flows from non-fish-bearing streams—

Hillslope gradient is a primary control when determining the type and magnitude of erosion processes occurring on a landscape (Dunne and Leopold 1978). NetMap provides estimates of potential erosion based on slope steepness and convergence, and topographic indicators derived from digital elevation models (Miller and Burnett 2007; Montgomery and Dietrich 1994). Erosion values from these models are a relative measure of the probability that sediment will reach a specific stream segment.

Debris flow potential is a quantitative measure of the potential for a landslide or debris flow to reach a specific stream reach. Burnett and Miller (2007) showed that a relatively small percentage of the landscape is needed to encapsulate the highest relative probabilities of debris-flow initiation and downstream traversal. Streams with high initiation probabilities are especially important as potential sources of wood for fish-bearing streams during landslides and debris flows (Benda and Dunne 1997a, 1997b; Reeves et al. 2003).

We used the debris-flow susceptibility tools in NetMap (Benda et al. 2007) for all streams in each watershed to identify both the erosion potential of slopes adjacent to fish-bearing streams and the debris-flow potential of non-fish-bearing streams. The debris-flow susceptibility tool in NetMap is based on Miller and Burnett (2007, 2008), and considers four topographic attributes: (1) channel slope, (2) valley width or confinement, (3) angles of tributary junctions, and (4) cumulative length of scour and deposition. Values derived indicate the relative potential for debris-flow movement through a reach. This model lacks a temporal component; therefore, debris-flow probability values are relative to each individual watershed. We used the upper quartile of debris-flow probability for each watershed to identify stream reaches with a high level of either erosion potential (for fish-bearing) or high debris-flow susceptibility (for non-fish-bearing). Reaches so identified were considered "most ecologically sensitive." [3]

Identifying "most ecologically sensitive" stream reaches—
Fish-bearing stream reaches with an intrinsic potential ≥0.5 or with an increase in thermal loading potential ≥10 percent or adjacent to areas of high erosion potential were placed in the "most ecologically sensitive" category, as were non-fish-bearing reaches with a high potential to deliver sediment and wood to fish-bearing streams (table 3). Stream reaches that did not meet any one of these criteria were placed in the "other" category.

Under option B, along the "most ecologically sensitive" reaches in fish-bearing and non-fish-bearing streams, the entire width of the one site-potential tree-height riparian conservation area would be managed solely for the goals of the ACS. Reaches classified as "other" could have an inner zone that varies in width, keyed to stream type: the inner zone is set at 100 ft (30.5 m) on fish-bearing streams and

[3] We approximated the high erosion-potential reaches for fish-bearing streams and the high debris-flow potential reaches in non-fish-bearing streams using the debris-flow potential algorithm of NetMap. More recent analysis of a subset of watersheds suggests that doing a separate analysis of each criterion would result in slightly more fish-bearing stream segments classified as "most ecologically sensitive" and slightly fewer non-fish-bearing streams placed in this category. These changes would largely balance out, having little or no effect on the acreage-weighted average percentages reported later in this report.

Table 4—Management in riparian conservation areas (RCAs) under option B

Management category	Stream type	Size of RCAs	Size of inner zone managed solely for ACS goals	Size of outer zone managed to achieve ACS goals and other goals[a]
Most ecologically sensitive	Fish-bearing	1 site-potential tree-height	1 site-potential tree-height	N/A
	Non-fish-bearing	1 site-potential tree-height	1 site potential tree-height	N/A
Other	Fish-bearing	1 site-potential tree-height	Edge of stream to 100 ft (30.5 m)	Edge of inner zone to a distance of 1 site-potential tree-height
	Non-fish-bearing	1 site-potential tree-height	Edge of stream to 50 ft (15.2 m)	Edge of inner zone to a distance of 1 site-potential tree-height

ACS = Aquatic Conservation Strategy; N/A = not applicable.
[a] Harvest can occur in stands currently less than or equal to 80 years of age using ecological forestry with tree-tipping.

50 ft (15.2 m) on non-fish-bearing streams (table 4 and fig. 8). As a result, we expect to minimize potential adverse effects of management on the aquatic ecosystem and to contribute to achieving ACS goals. The width of the inner zone on non-fish-bearing streams is based, in part, on Anderson et al. (2007) and Anderson and Poage (2014), who found that this distance reduces potential effects of harvest on water temperatures in small streams, as discussed under option A, and maintains microclimatic conditions, which is particularly important for amphibians. A 50-ft (15.2-m) inner zone also provides a corridor for amphibian movement along the stream network (Olson and Kluber 2014). The size of the inner zone on fish-bearing streams and the requirement for tree-tipping in the outer zone should maintain the suite of ecological processes, meeting the goals of the ACS.

Requiring variable-retention timber harvest under ecological forestry with tree-tipping in the outer zone on "other" streams, and limiting activity to stands currently less than or equal to 80 years of age, increases the likelihood of achieving ACS goals.

Requiring variable-retention timber harvest under ecological forestry with tree-tipping in the outer zone on "other" streams, and limiting activity to stands currently less than or equal to 80 years of age, also increases the likelihood of achieving ACS goals. Additionally, strategic placement of aggregate retention patches in the outer zone during variable-retention harvest (fig. 2) could increase the effective width of the inner zone beyond what is estimated here.

Relative to maintaining wood delivery processes to fish-bearing streams, option B has two components: (1) a one tree-height riparian conservation area devoted solely to achieving ACS goals on fish-bearing streams with high erosion potential and on non-fish-bearing streams with a high probability of debris-flow delivery to fish-bearing streams; and (2) a one tree-height riparian conservation area composed of an inner zone managed solely for the goals of the ACS and an outer zone managed to achieve ACS goals as well as other potential goals, which could include timber production. Overall, this forestry approach is designed to ensure maintenance of processes that deliver wood to streams.

Simulating the Potential Options for Managing Riparian Conservation Areas in Selected Watersheds

We chose six watersheds—Myrtle Creek, Applegate River, Coquille River, North Umpqua River, McKenzie River, and Smith/Siuslaw Rivers (fig. 4 and table 5)—to simulate the two options for managing riparian conservation areas. The Myrtle Creek and Coquille watersheds were chosen because they contain Secretarial Pilot Projects (see Johnson and Franklin 2012 for more discussion of these pilots). The Smith/Siuslaw was chosen because it had geologic features and soil stability different from the two pilot watersheds. The other three watersheds were chosen because they contain adaptive management areas designated under the NWFP. All watersheds are predominately forest lands (table 5). The Coquille, Smith/Siuslaw, and McKenzie support mostly moist forests, while the North Umpqua and Myrtle Creek have a mixture of moist and dry forests, and the Applegate is predominantly

Table 5—Size, land ownership, and distribution of fish-bearing and non-fish-bearing streams on federal and nonfederal land ownership for six case-study watersheds in western Oregon

	Watershed						
	Myrtle Creek	Applegate	Coquille	North Umpqua	McKenzie	Smith-Siuslaw	Weighted average
Total acres (total hectares)	76,207 (30 863)	260,525 (105 512)	381,629 (154 560)	591,772 (239 668)	608,072 (246 269)	784,948 (317 903)	450,526 (182 463)
Percentage of forest lands	93	92.6	93.5	84.7	89.9	97.1	91.7
Percentage of federal land ownership	41.6	72.7	39.7	66	65.9	56.9	59.6
Percentage of federal matrix	38.9	57.2	20.9	26.1	49.8	12.0	30.0
Percentage of BLM matrix	38.9	37	20.9	8.7	8.2	9.4	14.1
Miles of streams	562	1,957	2,859	3,556	3,945	5,840	3,970
Stream density (mi/1,000 ac)	7.9	8.1	8.0	7.1	7.2	7.7	7.5
Percentage of fish-bearing streams	41.9	29.1	34.8	17.4	22.4	46.6	31.3
Federal fish-bearing streams (mi/1,000 ac)	0.9	0.9	0.9	0.8	0.9	1.7	1.1
Nonfederal fish-bearing streams (mi/1,000 ac)	2.4	1.4	1.8	0.4	0.8	1.9	1.3
Federal non-fish-bearing stream (mi/1,000 ac)	2.1	4.6	2.1	4.6	3.5	2.5	3.3
Nonfederal non-fish-bearing stream (mi/1,000 ac)	2.5	1.2	3.1	1.3	2.1	1.6	1.8

Note: All information other than total acres is for the forested portion of the watershed.
BLM = Bureau of Land Management.

dry forest (fig. 1). All except the McKenzie watershed contain critical habitat for the ESA-listed coho salmon (Oregon Coast and Southern Oregon/Northern California Evolutionarily Significant Units) (fig. 5). The McKenzie has critical habitat for Willamette Chinook salmon, steelhead, and bull trout (*Salvelinus confluentus*) (fig. 5).

The proportion of federal ownership of forests ranges from 42 to 73 percent and proportion of federal matrix from 12 to 57 percent of the total forest area, depending on the watershed (table 5 and fig. 4). Most of the remaining forest is privately owned, with the forest industry being the predominant private owner except in the Myrtle Creek and Applegate watersheds, where substantial nonindustrial private (e.g., family forest) ownerships occur. Fish-bearing streams range from 17.4 to 47 percent of the total stream network, depending on the watershed (table 5), with an acreage-weighted average of 31 percent. Federal forests averaged a lower density of fish-bearing streams than did nonfederal forests in most watersheds, and a higher density of non-fish-bearing streams in all but two of the watersheds (table 5).

Lands allocated as BLM matrix, the focus of analysis, covered an average of 14.1 percent (range 8.2–38.9 percent) of the watersheds or a total of 381,527 ac (table 6a). Given a total BLM matrix area in western Oregon (including riparian reserves) of 1,219,548 ac (USDI BLM 2015, p. 29), our study watersheds cover approximately 31 percent of BLM matrix in western Oregon.[4]

The analysis of each of our six study watersheds consisted of four steps: (1) delineate the fish-bearing and non-fish-bearing streams; (2) using the delineated stream networks, map current riparian policy on federal and private lands, for comparison; (3) map option A; (4) classify stream segments based on aquatic ecological sensitivity criteria for option B and assign the width of inner zones and outer zones in matrix based on the classification (fig. 11).

Step 1: Delineate the stream network and categorize the streams into fish-bearing and non-fish-bearing—

NetMap (Benda et al. 2007) delineates the streams in the watershed using a "catchment basin" approach. The initiation size for a stream varies with slope (steeper areas require less area and a shorter stream length than less-steep areas) and planform curvature (Clarke et al. 2008, Miller 2003). To validate the accuracy of NetMap-modeled stream networks, we compared our results to BLM and Oregon Department of Forestry (ODF) data sets of field-verified stream networks in the

[4] The Eastside Management Area shown on page 29 of the *Western Oregon Draft RMP/EIS* (USDI BLM 2015) is excluded from the analysis because it lies outside the area of the Northwest Forest Plan.

Table 6a—Distribution of area in interim riparian reserves in matrix among different categories undercurrent policy and potential options A and B for six case-study watersheds on Bureau of Land Management lands in western Oregon

		Estimated total area in interim riparian reserves										
				Option A			Option B					
		Current policy			Non-fish		Most ecologically sensitive		Other streams, fish		Other streams, non-fish	
Watershed	Total BLM matrix	Fish	Non-fish	Fish	Inner zone	Outer zone	Fish	Non-fish	Inner zone	Outer zone	Inner zone	Outer zone
						Acres						
Myrtle Creek	29,655	4,413	4,624	2,236	2,522	2,624	1,376	1,089	525	334	1,188	2,872
Applegate	96,400	10,420	20,640	5,354	10,960	10,760	3,293	7,892	1,302	760	4,173	9,662
Coquille	80,149	15,630	16,470	8,246	9,081	8,891	3,529	4,420	2,267	2,449	3,067	10,490
North Umpqua	51,261	4,395	10,760	2,268	5,730	5,487	1,501	2,401	420	347	2,457	6,365
McKenzie	49,950	8,367	7,960	4,366	4,323	4,214	2,660	1,921	900	805	1,861	4,759
Smith/Siuslaw	74,113	23,610	11,510	12,440	6,860	7,690	6,794	4,234	2,566	3,077	1,957	8,359
Total	381,527	66,835	71,964	34,910	476	39,666	19,153	21,957	7,980	7,772	14,703	42,507

Fish = fish-bearing streams. Non-fish = non-fish-bearing streams.

Table 6b—Proportion of matrix in interim riparian reserves under current policy and division of that proportion among different management objectives under potential options A and B for six case-study watersheds on Bureau of Land Management lands in western Oregon

	Proportion of matrix under different management objectives						
	Current policy	Option A			Option B		
Watershed	ACS goals	ACS goals	Dual goals	Matrix goals	ACS goals	Dual goals	Matrix goals
Myrtle Creek	0.30	0.16	0.09	0.06	0.14	0.11	0.06
Applegate	0.32	0.17	0.11	0.04	0.17	0.11	0.04
Coquille	0.40	0.22	0.11	0.07	0.17	0.16	0.07
North Umpqua	0.30	0.16	0.11	0.03	0.13	0.13	0.03
McKenzie	0.33	0.17	0.08	0.07	0.15	0.11	0.07
Smith/Siuslaw	0.47	0.26	0.10	0.11	0.21	0.15	0.11
Weighted average	0.36	0.19	0.10	0.06	0.17	0.13	0.06

ACS = Aquatic Conservation Strategy.

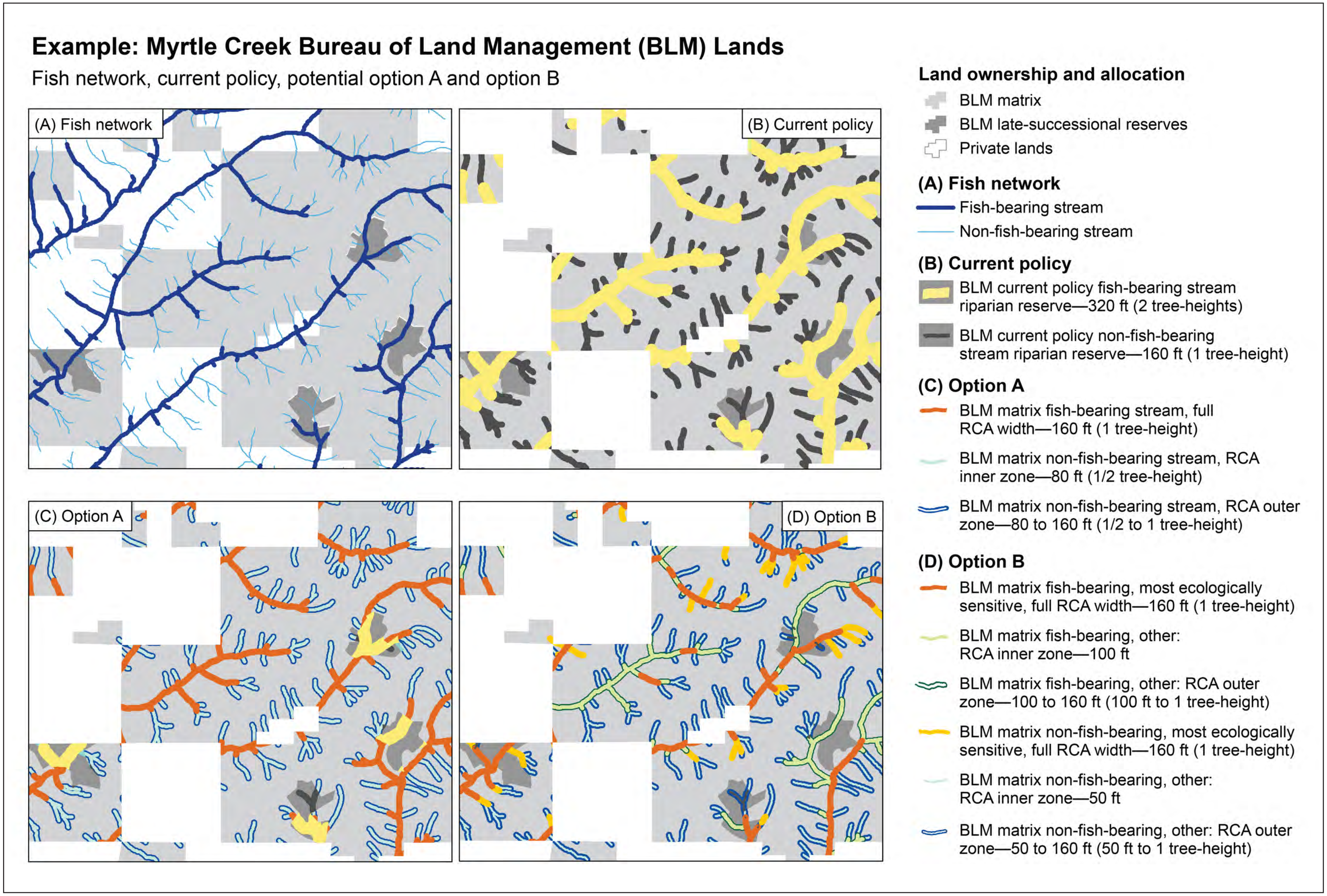


Figure 11—Example of the process of analysis for each study area. A small area of the Myrtle Creek watershed was used for these examples. The stream categories are not shown here.

Smith/Siuslaw and Myrtle Creek watersheds. Based on our initial validation assessment, we found that we slightly underestimated the initiation points of headwater streams (they originate higher in the watershed than we determined using NetMap), which would cause us to slightly underestimate the extent of non-fish-bearing streams.

We also compared the fish-bearing determinations between the NetMap analysis and the BLM and ODF data sets. We used a gradient of 10 percent to differentiate fish-bearing from non-fish-bearing streams. Stream reaches with a maximum downstream gradient of <10 percent are considered fish-bearing, hosting primarily anadromous and resident salmonids. Stream reaches with a maximum downstream gradient >10 percent are considered non-fish-bearing, although non-salmonid fishes such as sculpins (*Cottus* spp.) may be found there. There was approximately 90-percent agreement between the NetMap-predicted fish distribution and agency data sets, with the main difference that the NetMap layer included reaches determined as fish-bearing that BLM and ODF designated as non-fish-bearing. A potential reason for this difference is that ODF field verifications assume that there are no fish-bearing reaches above the first non-fish-bearing reach. In contrast, we identified the uppermost reach with <10-percent gradient and designated everything downstream as fish-bearing. Our NetMap analysis was based on the best available topographic data available at the time—10-m digital elevation models—which are not able to discern small, abrupt changes in stream gradient.

As should be expected, the criteria for delineating non-fish-bearing streams influenced our results (fig. 12). Had we used a higher gradient threshold to differentiate fish-bearing from non-fish-bearing streams, our analyses could have contained higher proportions of fish-bearing streams, which affects the proportion of the riparian conservation area managed strictly for ACS objectives. Given an increase in the gradient threshold for fish-bearing streams, the proportion of the landscape in which timber production could be one of the goals would decrease under option A, where fixed-width riparian conservation areas are uniformly applied to all fish-bearing streams. Under option B, where the width of the zone managed solely for ACS goals is a function of the ecological context of the stream reach, there would also be reduction in area available for timber production with an increase in stream-gradient threshold, but less so than under option A. The ability to modify parameters based on observed site conditions or new knowledge is a strength of the NetMap method; fundamental conclusions about the relative effectiveness of the options evaluated here remain sound even if the parameters for identifying fish-bearing streams were to be modified.

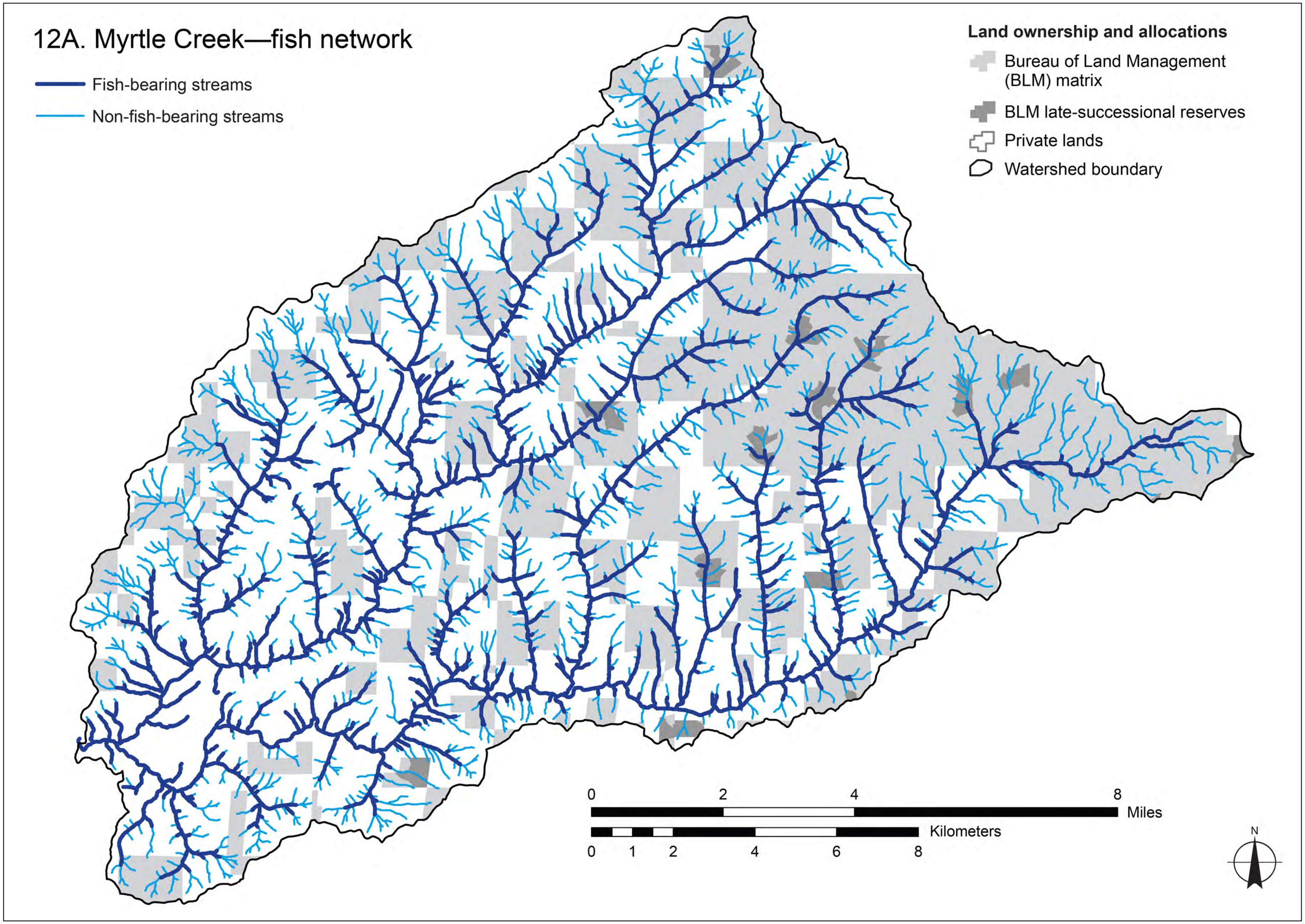
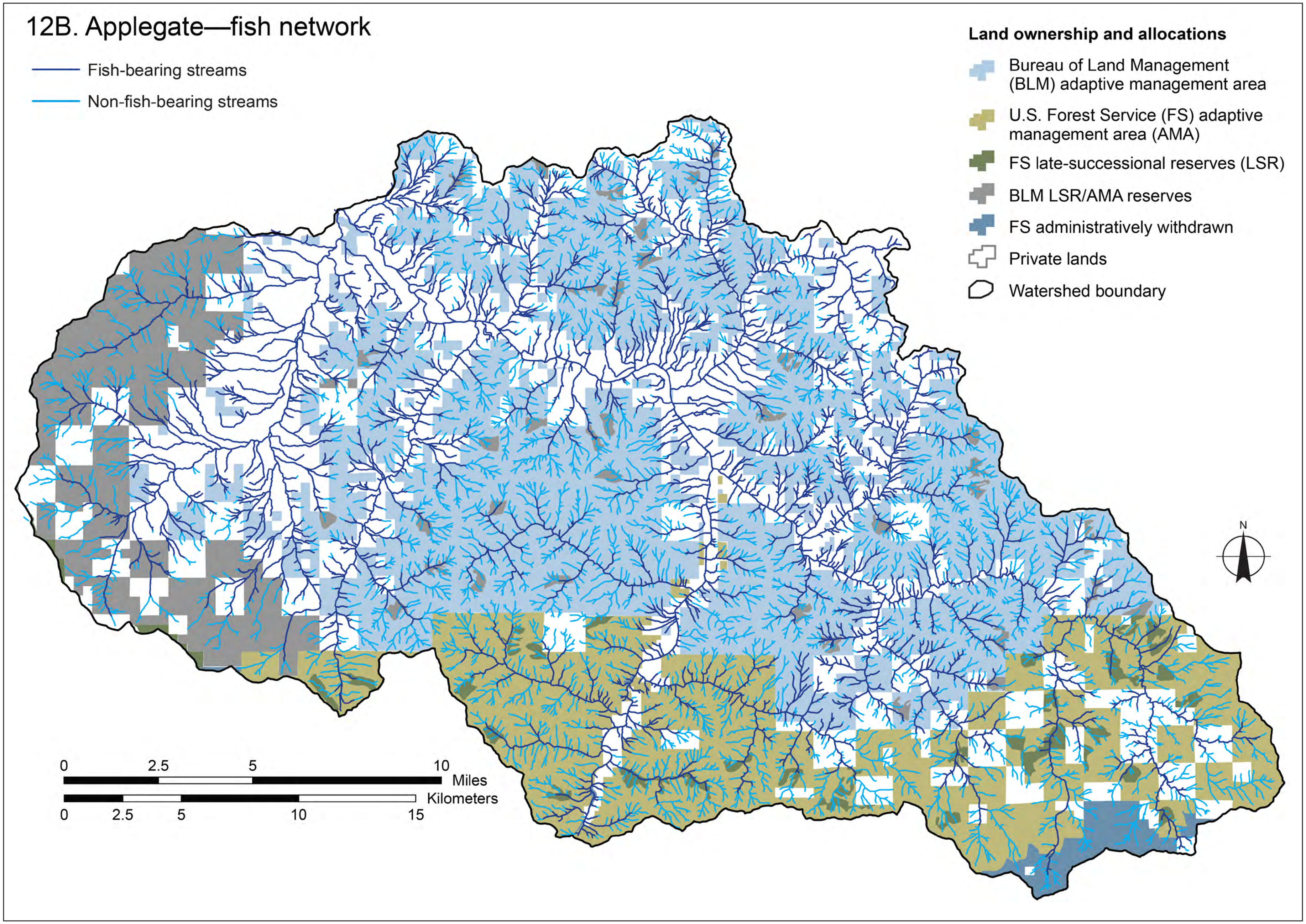


Figure 12—Streams delineated as fish-bearing or non-fish-bearing in the six study watersheds. (A) Myrtle Creek; (B) Applegate; (C) Coquille; (D) North Umpqua; (E) McKenzie; (F) Smith/Siuslaw.



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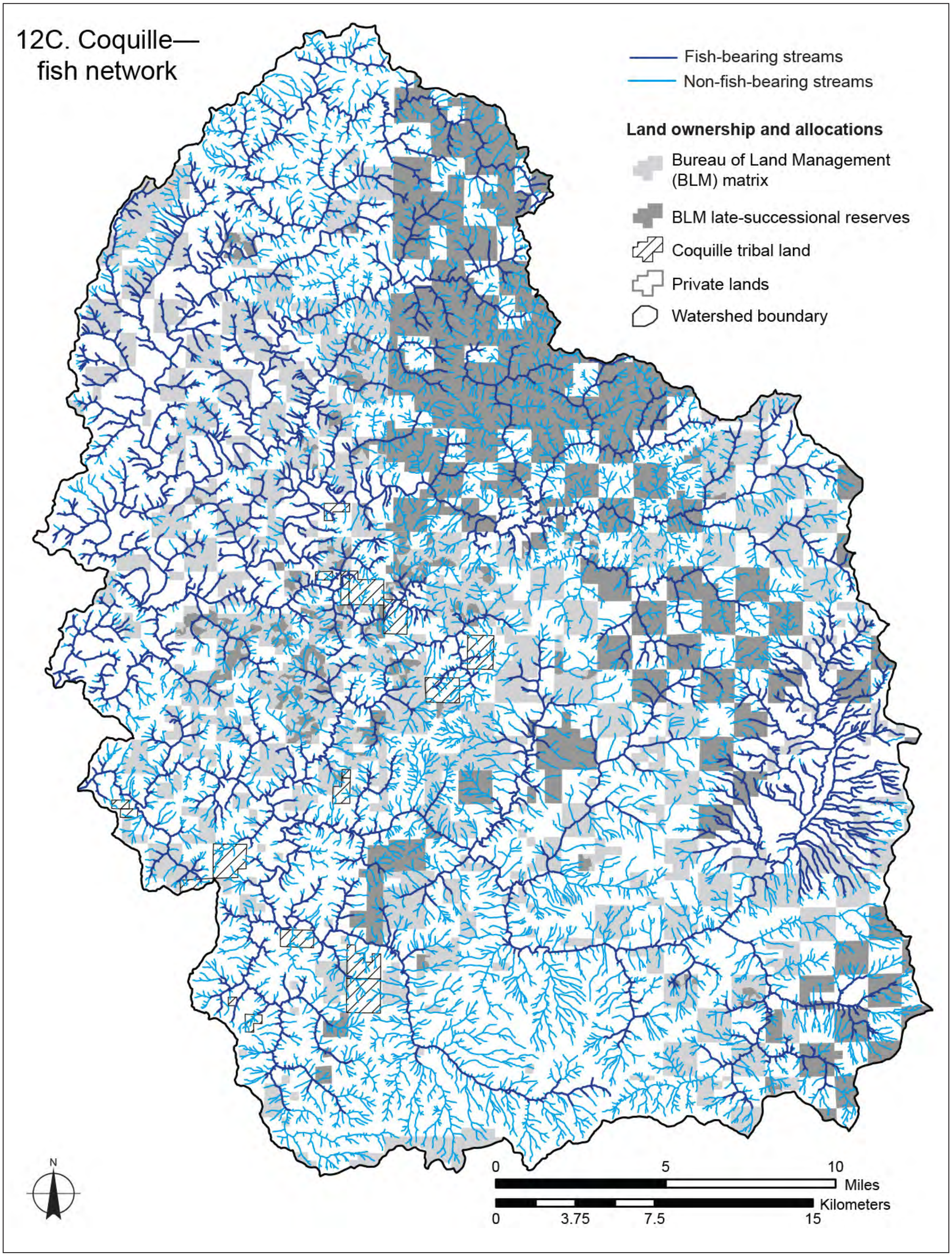

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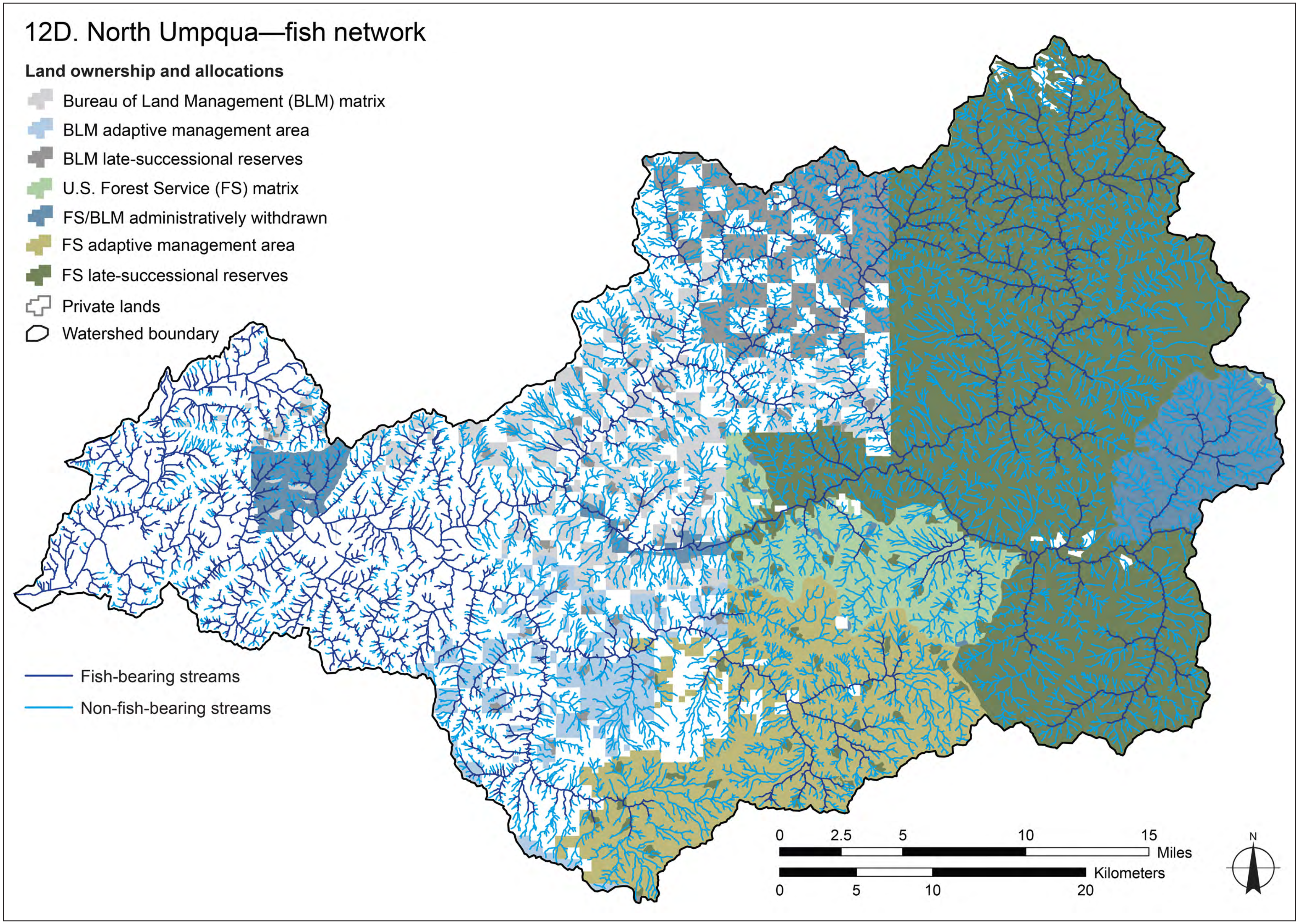

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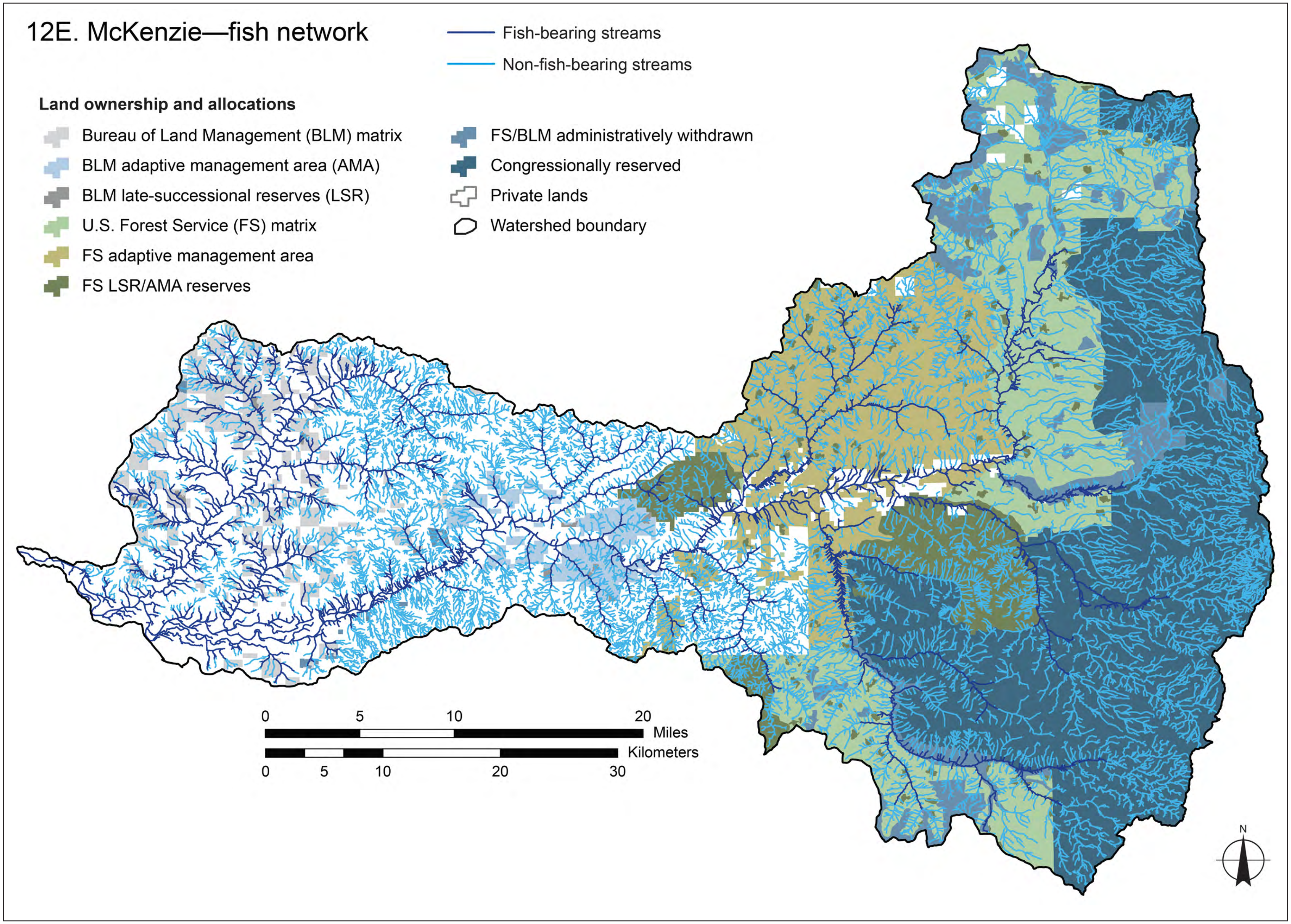

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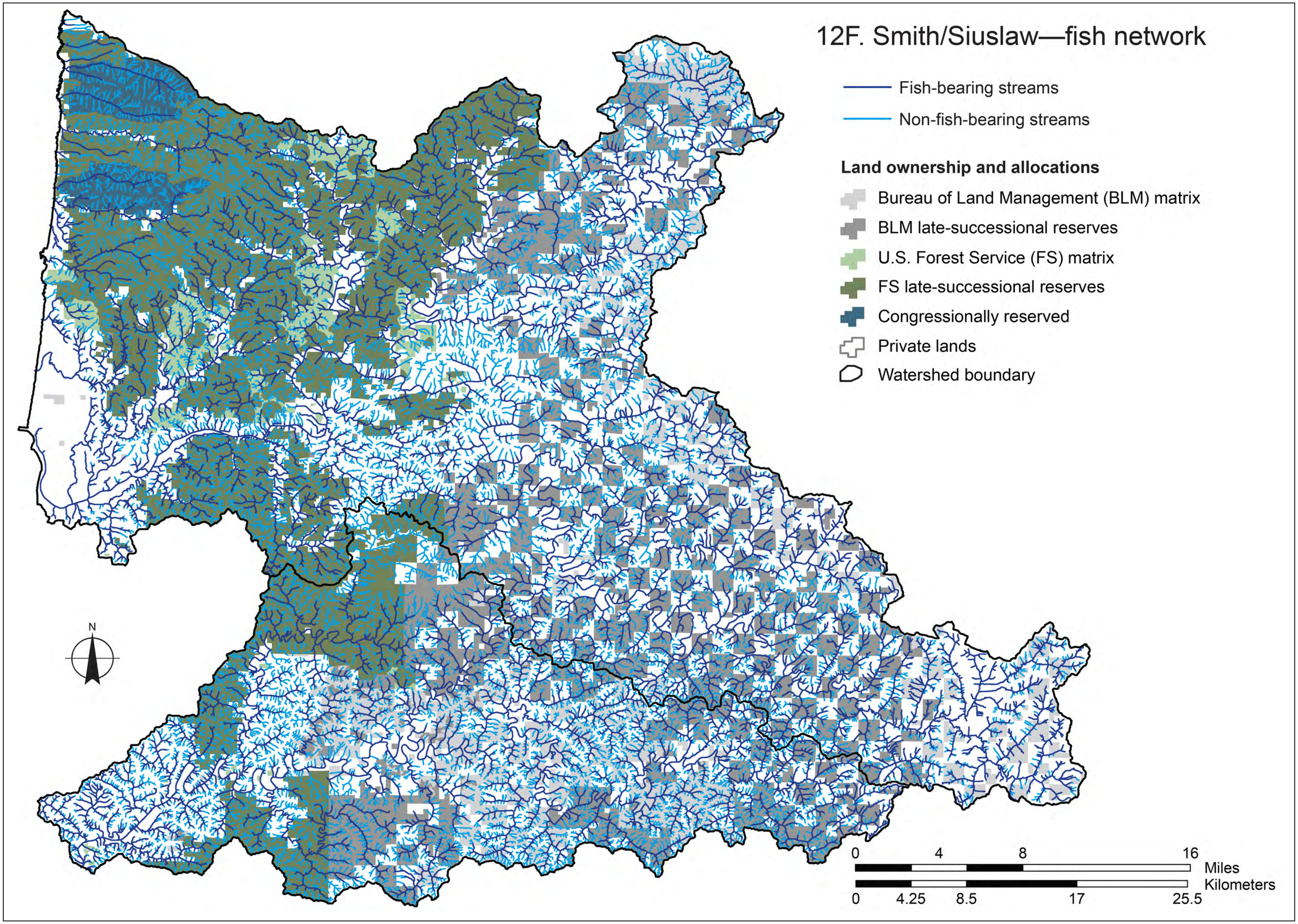

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Step 2: Simulate current riparian management policy—
The NWFP calls for interim riparian reserves of two site-potential tree-heights along each side of fish-bearing streams and one site-potential tree-height along each side of non-fish-bearing streams, with a minimum width of 300 ft (91.4 m) on each side of fish-bearing streams and 150 ft (45.7 m) on each side of non-fish-bearing streams (fig. 13) (USDA and USDI 1994). On BLM forests in our study, a site-potential tree-height varies from 155 to 220 ft (47.2 to 67.1 m) (table 7). Thus, riparian reserve widths vary from 310 to 440 ft (94.4 to 134.2 m) on each side of a fish-bearing stream and 160 to 220 ft (48.7 to 67.1 m) on each side of a non-fish-bearing stream (table 7), which results in interim riparian reserves covering an average of 36 percent of the acre-weighted area of BLM matrix lands in the six study watersheds (table 6b). For comparison, TNC/WSC (2012, p. 5) estimated that interim riparian reserves cover 37 percent of BLM western Oregon forests, and the BLM (2015, p. 28 and 32) estimated that interim riparian reserves cover 38 percent of its western Oregon forests and 43 percent of matrix lands in these forests under the No Action (Northwest Forest Plan) alternative.[5]

Table 7—Modeled site-potential tree-heights and riparian reserve widths on federal lands under current implementation of the Aquatic Conservation Strategy of the Northwest Forest Plan

			Width of riparian reserve each side of stream	
Watershed	Ownership	Site-potential tree-height	Fish-bearing	Non-fish-bearing
		Feet		
Myrtle Creek	BLM	160	320	160
Applegate	BLM/USFS	155	310	155
Coquille	BLM	210	420	210
North Umpqua	BLM/USFS	180/200	360/400	180/200
McKenzie	BLM/USFS	180/200	360/400	180/200
Smith/Siuslaw	BLM/FS	220/250	440/500	220/250

BLM = Bureau of Land Management; USFS = U.S. Forest Service.
Source: personal communications from federal managers on districts and national forests.

For perspective, we simulated the designated widths of the riparian management areas for private lands under the Oregon Forest Practices rules (Adams and Storm 2011, ODF 2014). Those rules specify different maximum sizes of buffers based on rate of streamflow and whether or not the stream reach is a domestic water source or potentially contains fish (fig. 13; table 8). Within that maximum riparian

[5] The Eastside Management Area shown on pages 28 and 32 of the *Western Oregon Draft RMP/EIS* (USDI BLM 2015) is excluded from the analysis because it lies outside the area of the Northwest Forest Plan.

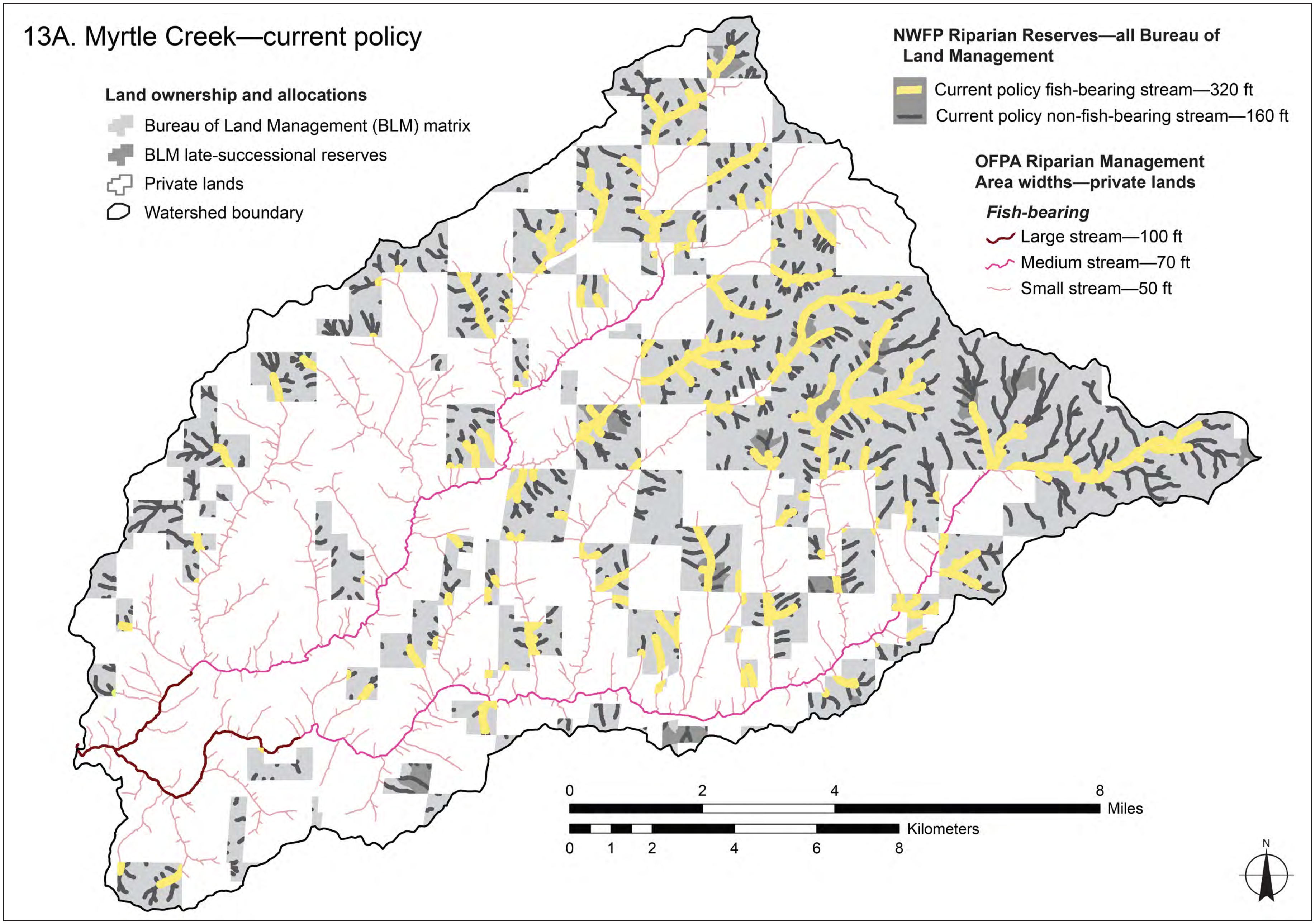
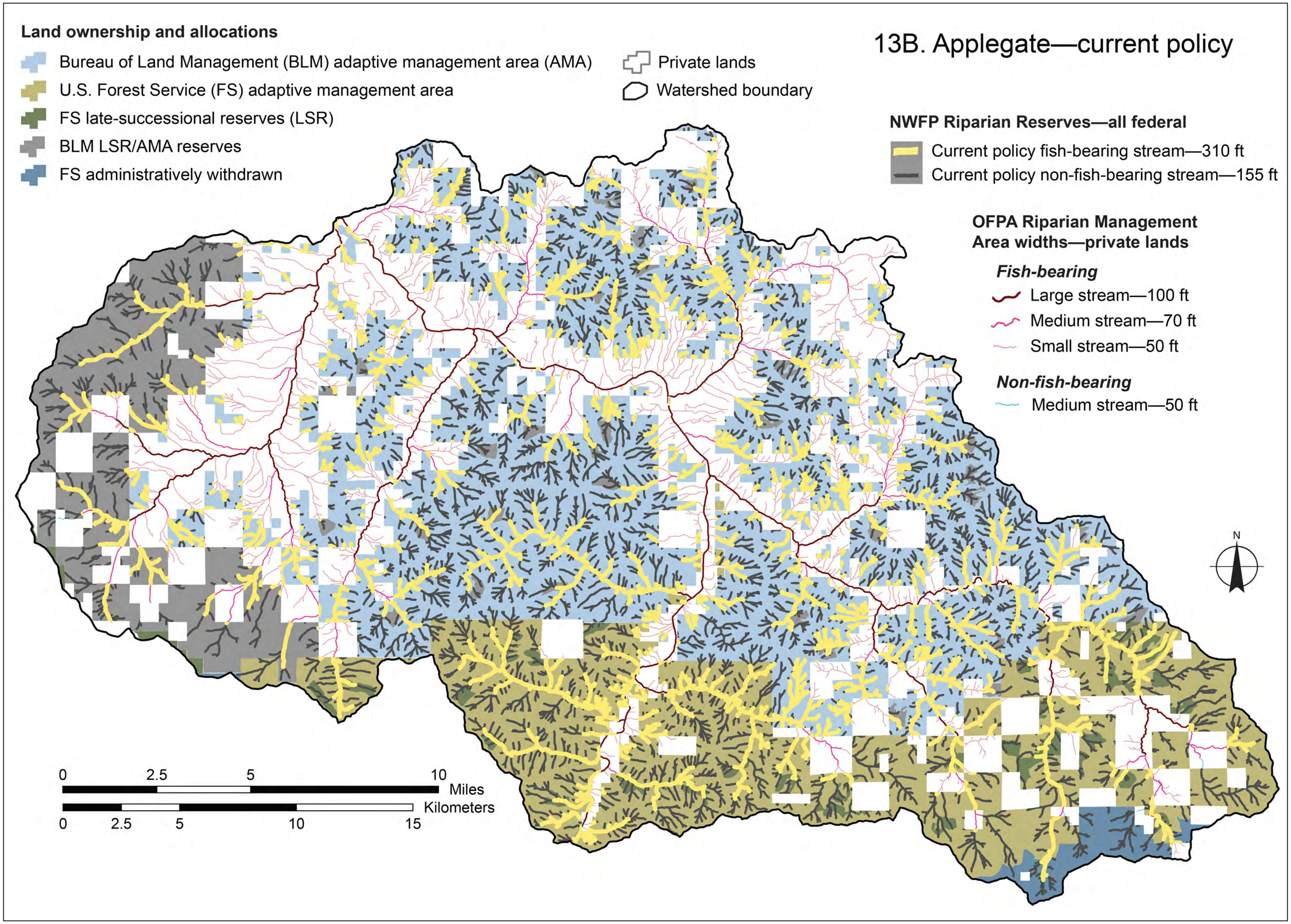


Figure 13— Northwest Forest Plan interim riparian reserves (current policy) mapped for the six study watersheds. (A) Myrtle Creek; (B) Applegate; (C) Coquille; (D) North Umpqua; (E) McKenzie; (F) Smith/Siuslaw. NWFP = Northwest Forest Plan; OFPA = Oregon Forest Practices Act.



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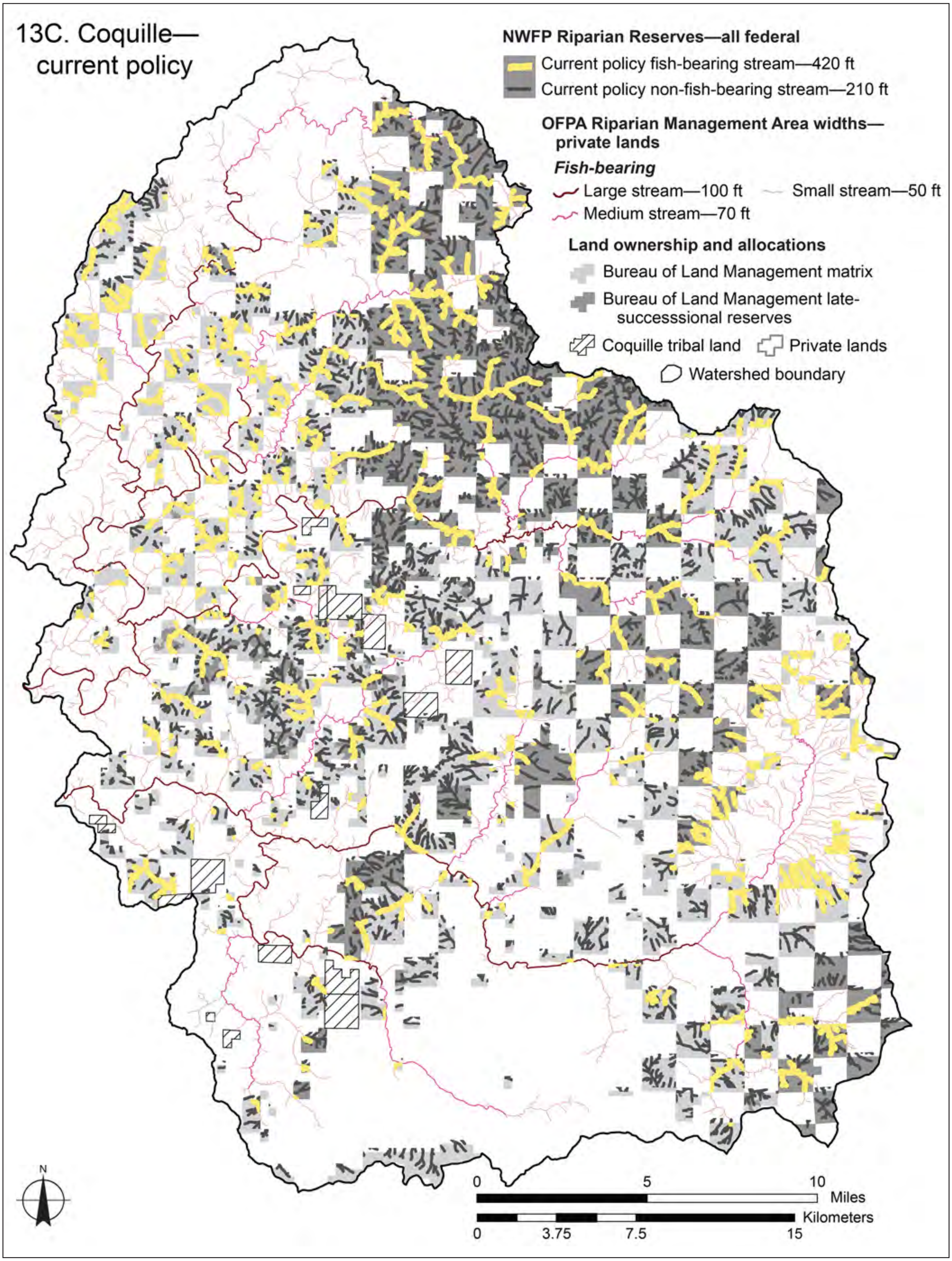

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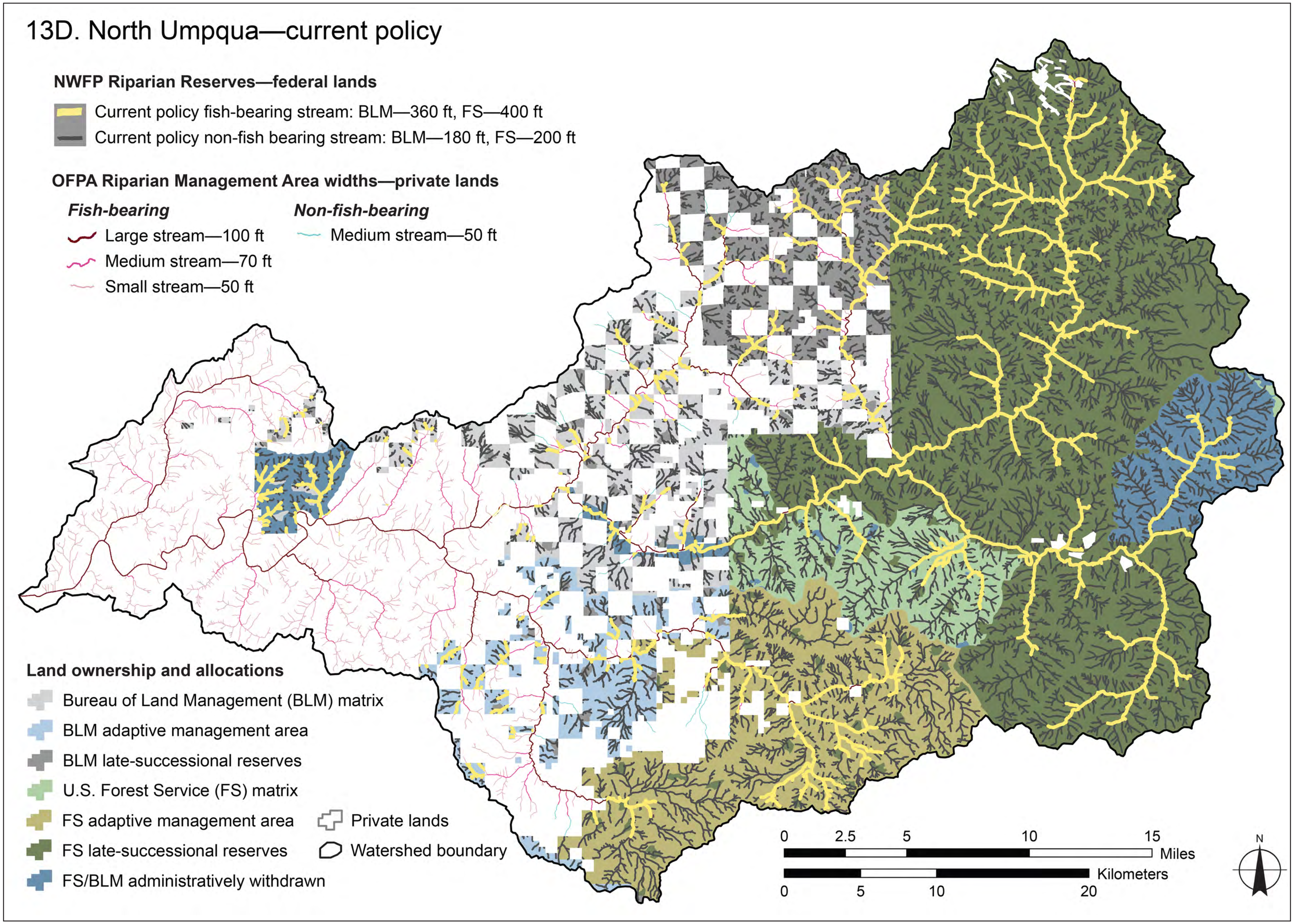

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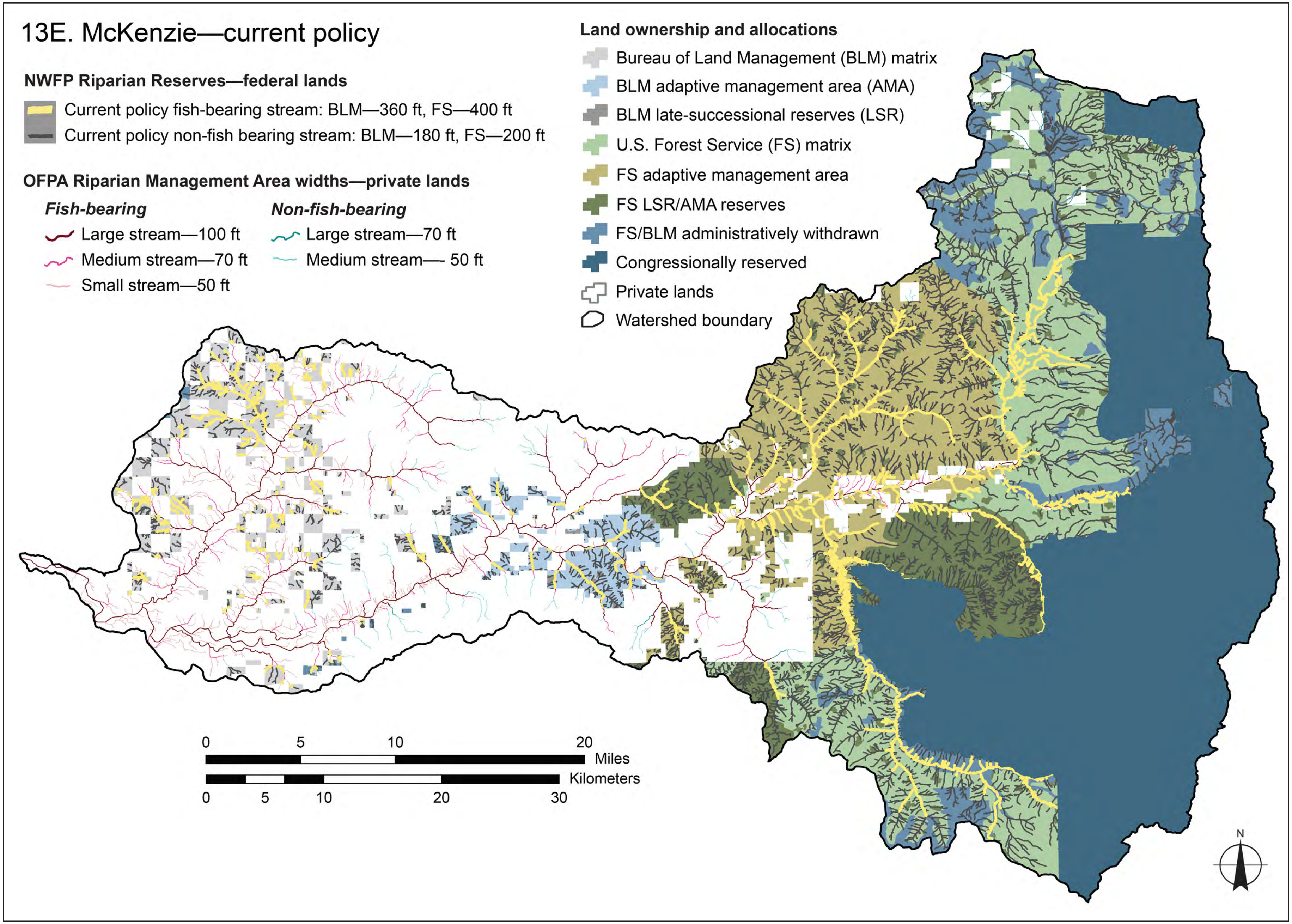

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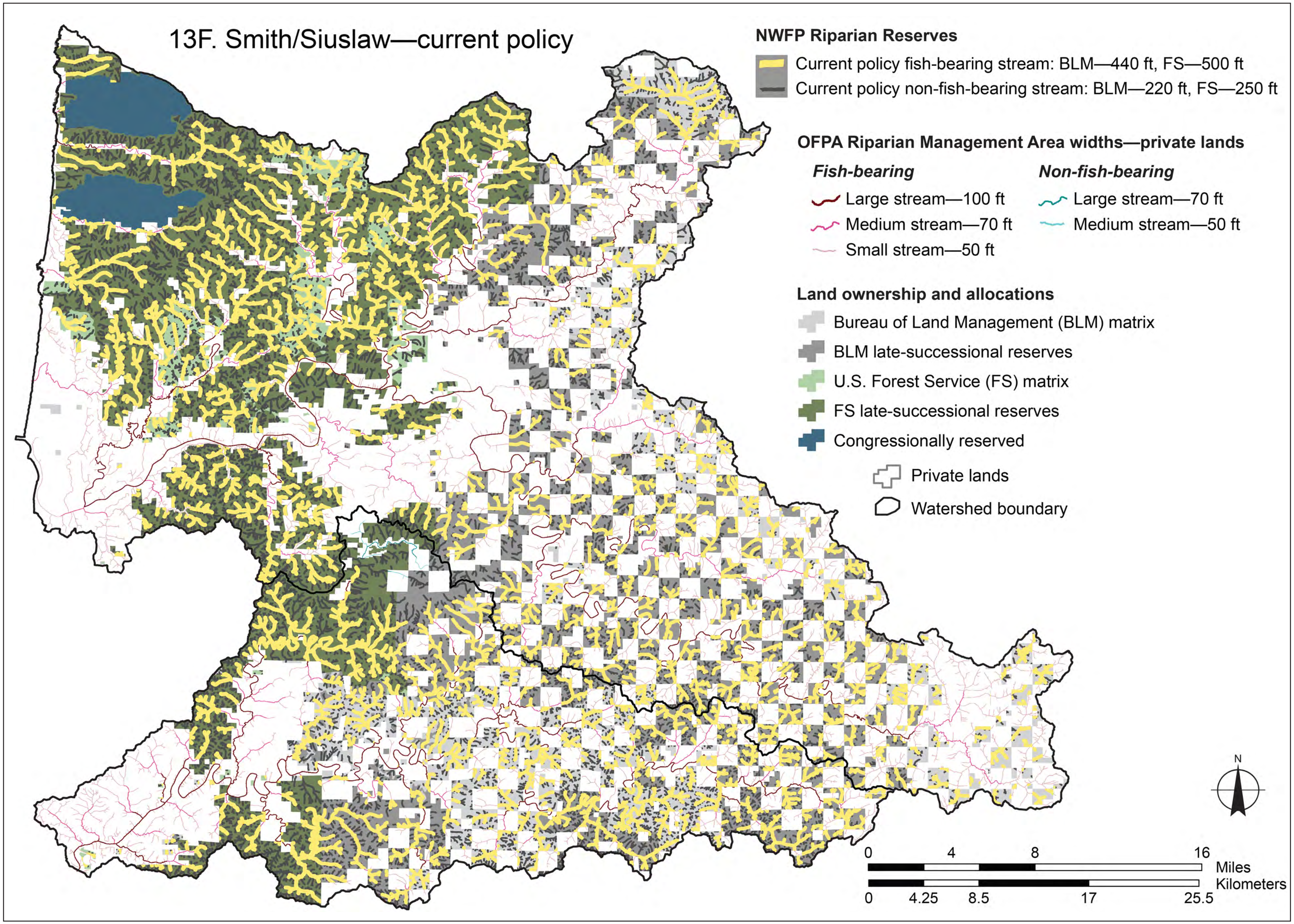

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Table 8—Maximum size of riparian management areas in different types and sizes of streams under the Oregon State Forest Practices rules

	Stream type		
Stream size	Type F (used by fish)	Type D (source of domestic water)	Type N (all other streams)
Large	30.5 m (100 ft)	21.4 m (70 ft)	21.3 m (70 ft)
Medium	21.4 m (70 ft)	15.2 m (50 ft)	15.2 m (50 ft)
Small	15.2 m (50 ft)	6.1 m (20 ft)	Coast and Cascades: 0 m (0 ft)[a]
			Southwest Oregon: Retain understory vegetation and conifers ≤15.2 cm (6 in) dbh for 3 m (10 ft) on either side of the stream on portions of certain perennial non-fish-bearing streams.

[a] The value for the Coast and Cascades, 0 m (0 ft), was used in our modeling simulations.
Sources: Adams and Storm (2011), ODF (2014). http://www.oregon.gov/odf/privateforests/docs/fparulebk.pdf.

management area width for a particular stream type, a specified level of tree basal area must be achieved before trees can be removed. If that target basal area can be achieved in less area than the maximum width, the buffer width can be reduced somewhat, but to no less than 20 ft (6.1 m) from the stream. For private lands in our study watersheds, we used the maximum widths specified in table 8 for our analyses. Our simulations suggest that about 6 percent of the forest area on private lands falls within the maximum riparian management area widths. This result is similar to that found in the Oregon Coast Range in other studies (Johnson et al. 2007).

Step 3: Simulate Option A: a fixed-width division of the riparian conservation area between inner and outer zones—
As described previously, under option A, the full width of the one site-potential tree-height riparian conservation area along fish-bearing streams and the inner zone of one-half site-potential tree-height on non-fish-bearing streams could be managed solely for the goals of the ACS (fig. 14). An outer zone on non-fish-bearing streams equal to the additional one-half a site-potential tree-height could be managed to achieve the goals of the ACS as well as for timber production and other goals (fig. 8). Ecological forestry with tree-tipping could be used in the outer zone.

Step 4: Simulate option B: a context-dependent division of the riparian conservation area between inner and outer zones based on ecological sensitivity—
We classified each steam segment in our study watersheds into "most ecologically sensitive" and "other" based on our site criteria (table 3). The full one site-potential tree-height width of the riparian conservation area for the "most ecologically sensitive" reaches and the inner zone along "other" streams could be managed solely for the goals of the ACS. The outer zone for "other" streams could be managed with

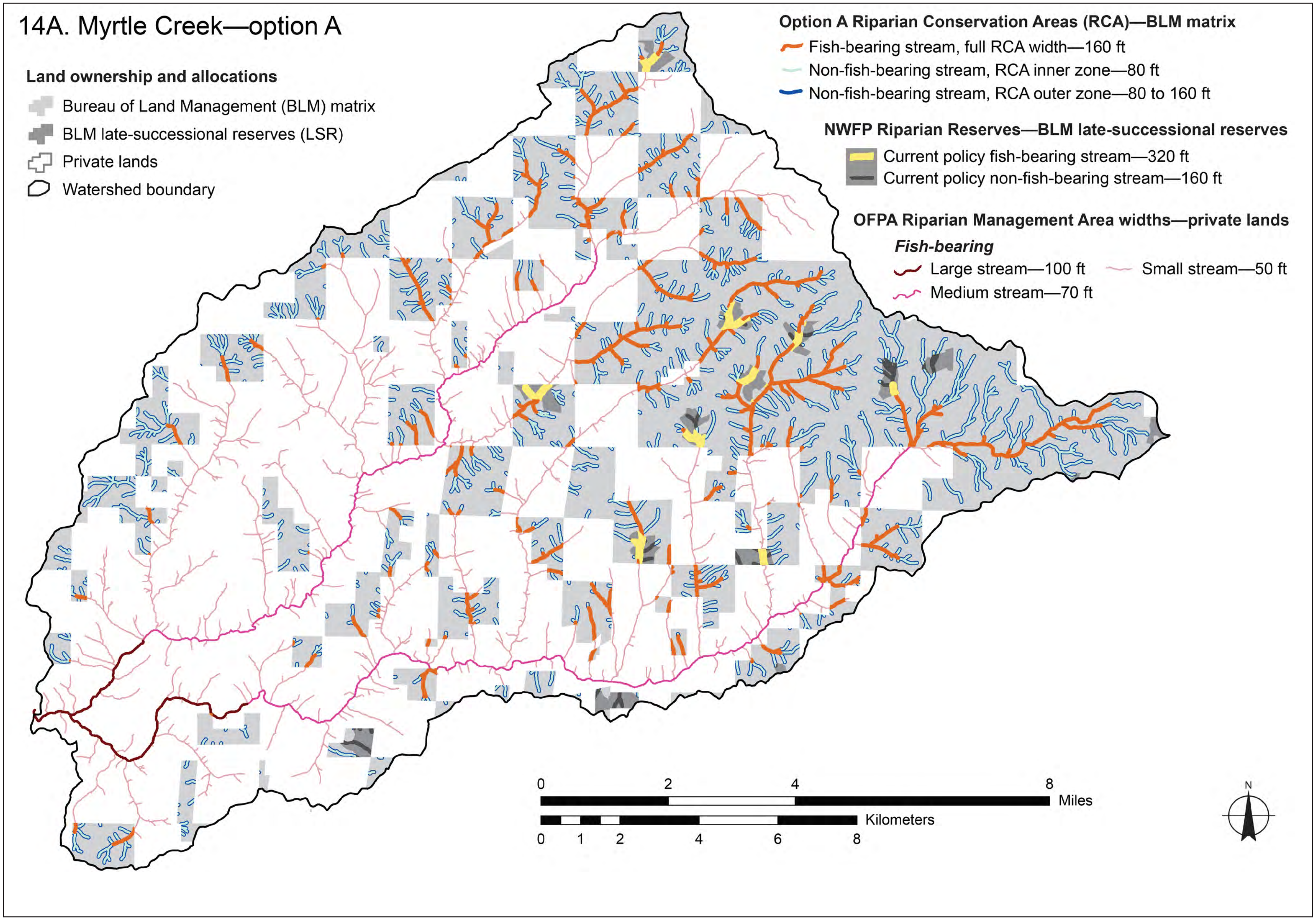
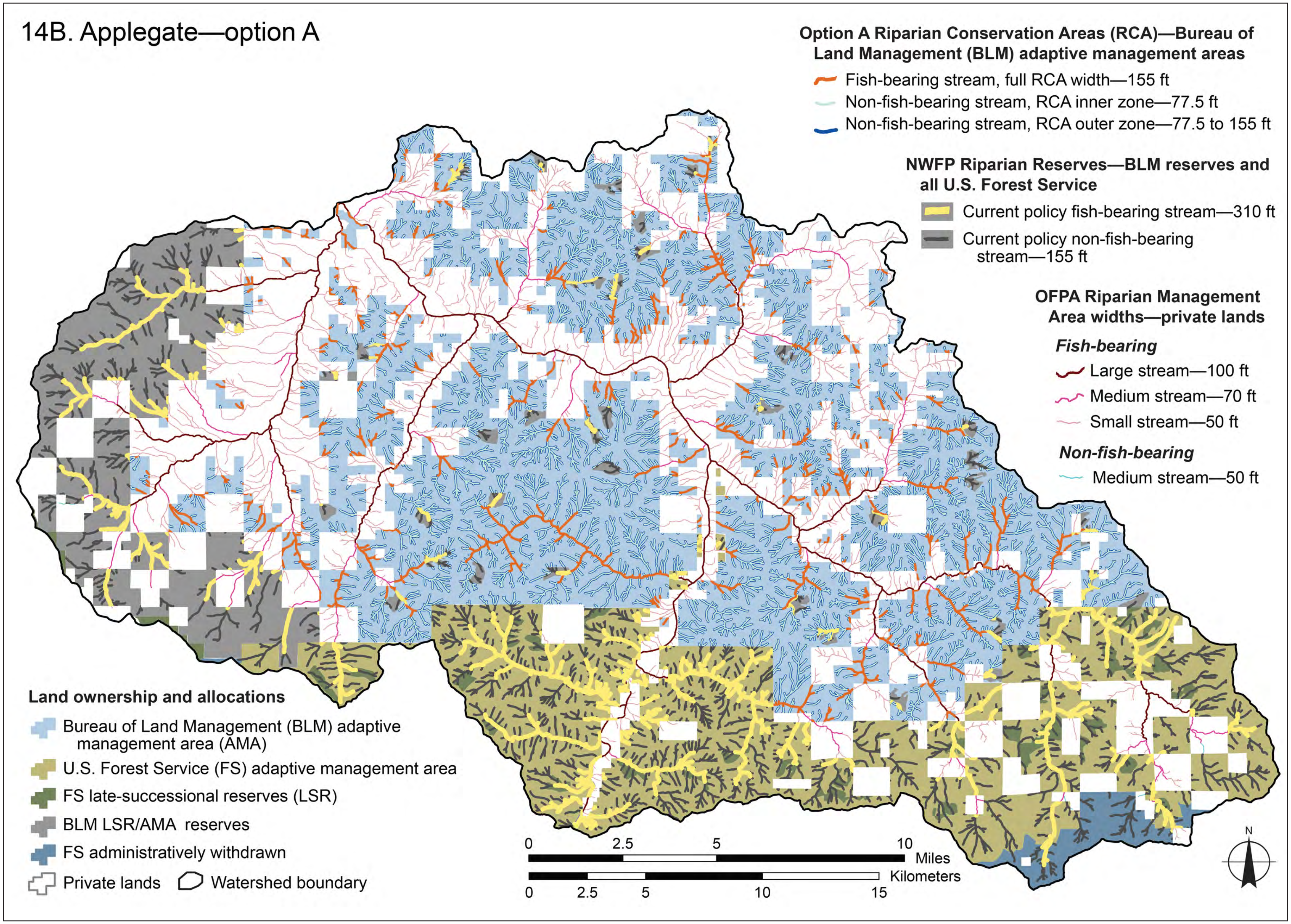


Figure 14—Simulation of option A riparian conservation area zones for the six study watersheds. (A) Myrtle Creek; (B) Applegate; (C) Coquille; (D) North Umpqua; (E) McKenzie; (F) Smith/Siuslaw. NWFP = Northwest Forest Plan; OFPA = Oregon Forest Practices Act.



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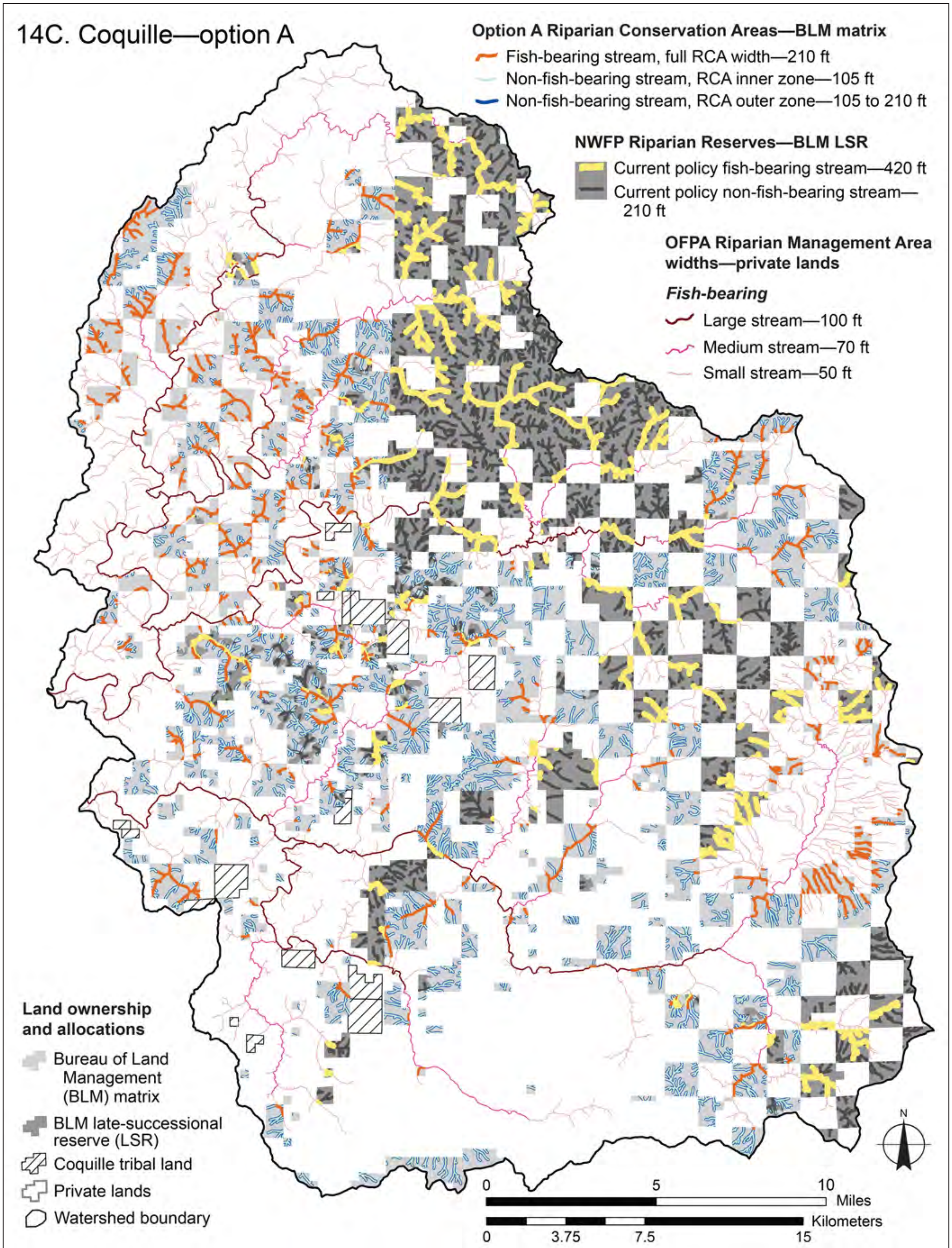

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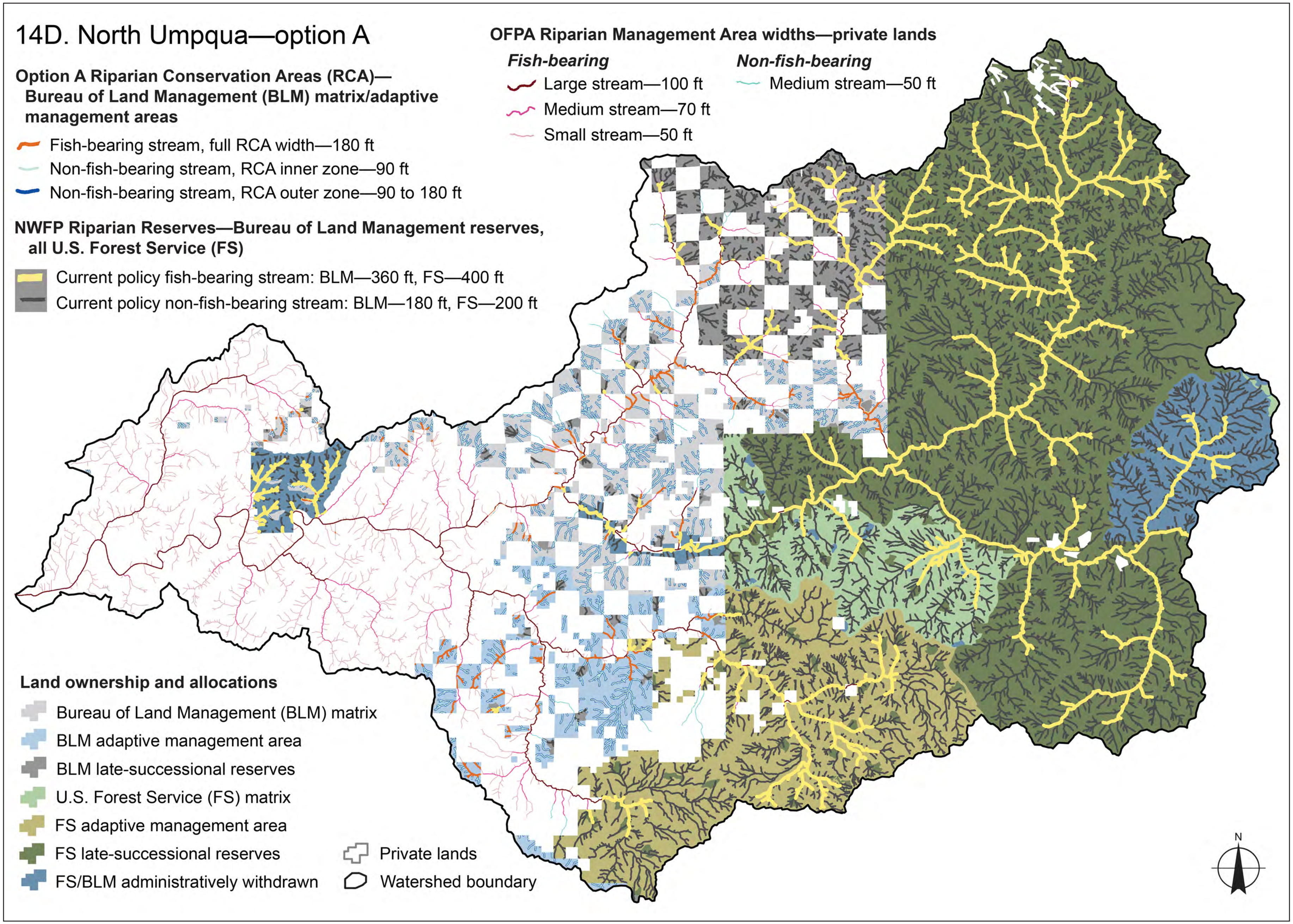

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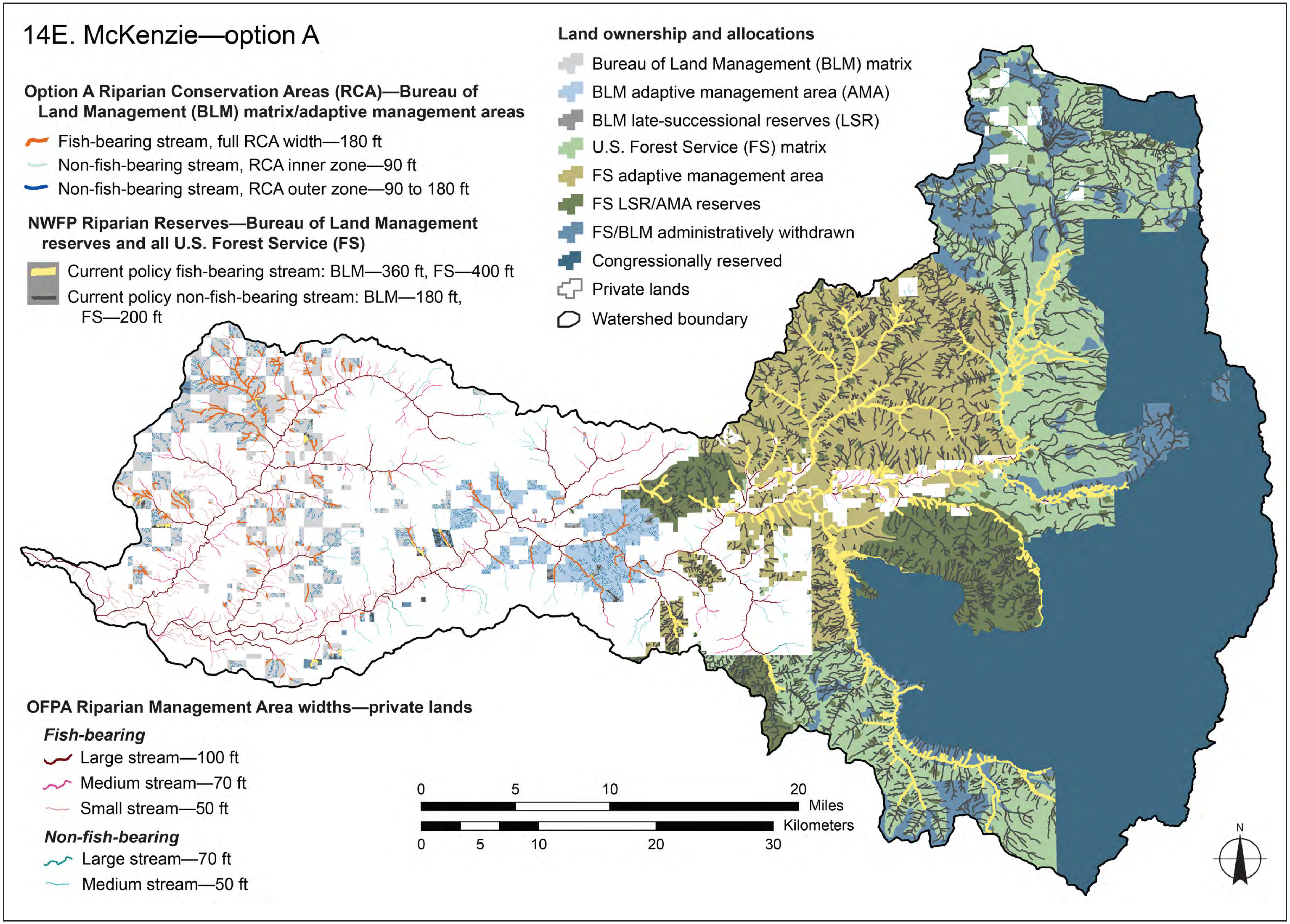

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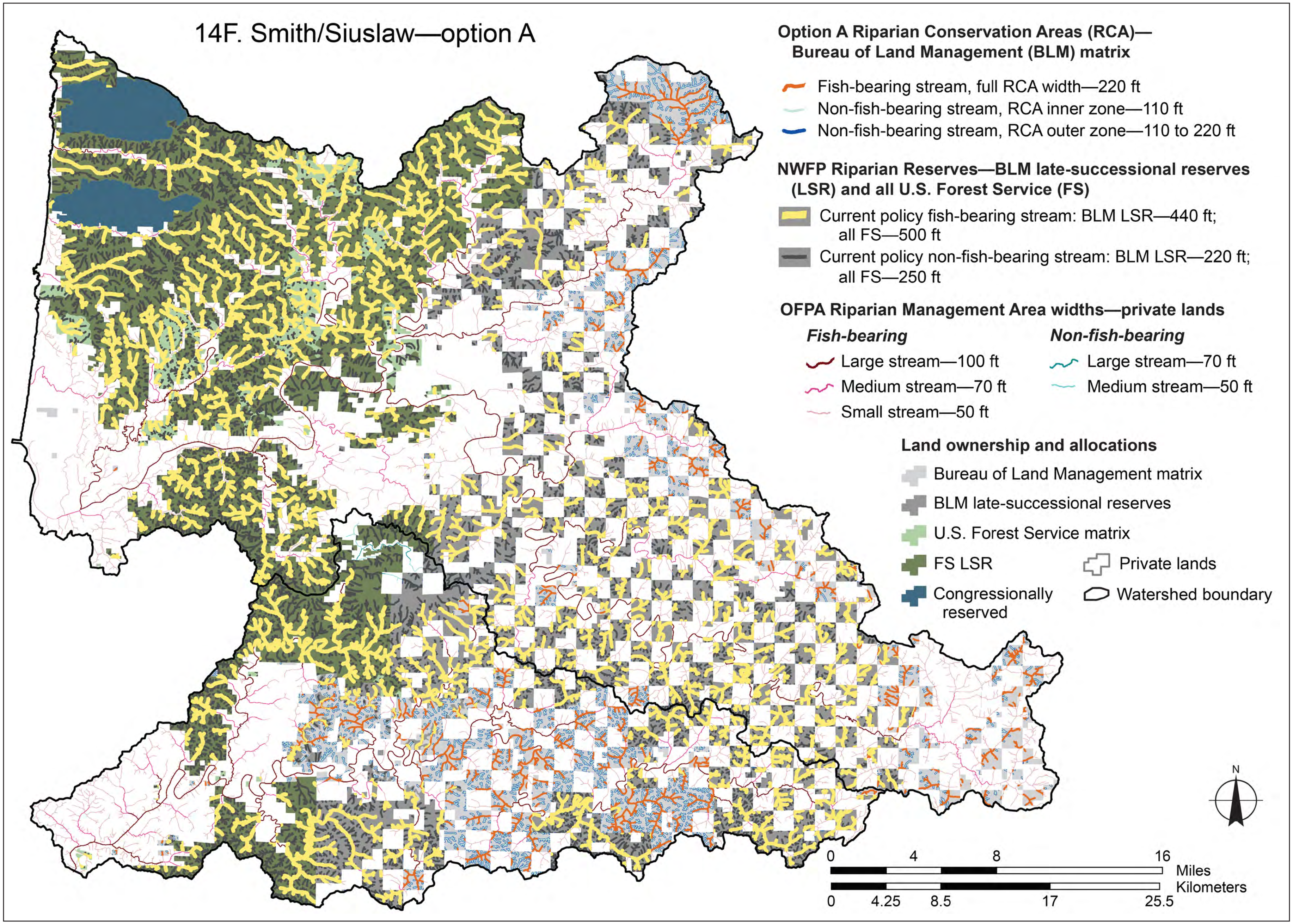

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timber production as an additional goal, using ecological forestry with tree-tipping. Figure 15 demonstrates the stream segment delineation in the six study watersheds. We then applied the prescribed width of the different zones (table 4; fig. 8) to the classified streams (fig. 16)

In our study, an average of 63 percent (range of 54–74 percent) of fish-bearing stream miles across all ownerships were classified as "most ecologically sensitive," depending on watershed, as were an average of 28 percent (range 23–32 percent) of non-fish-bearing streams (table 9). In aggregate, an average of 38 percent (range 37–40 percent) of the stream network across all ownerships was classified as "most ecologically sensitive."

Division of the Interim Riparian Reserves Among Different Goals Under the Two Options

In matrix—

Compared to the NWFP, the two potential options evaluated here reduce the portion of the interim riparian reserves in the BLM matrix that has achievement of the goals of the ACS as a primary objective by approximately 18 percent (range 11–23 percent) (table 10). This reduction results from changing the area of riparian reserves in matrix from two site-potential tree-heights to one site-potential tree-height on fish-bearing streams. Under both options, the forest in this second tree-height in BLM matrix would shift to the terrestrial prescription in the NWFP, which generally has timber production as one of the management objectives.[6]

The remainder of existing interim riparian reserves in BLM matrix—one tree-height on all streams—could be divided into two parts (table 10): 1) an average of 54 percent (range 53–55) and 46 percent (range 41–54) in options A and B, respectively, could continue to be managed solely for the goals of the ACS; 2) the remainder, an average of 29 percent in option A (range 22–36) and 36 percent in option B (range 33–44), could be managed jointly for ACS and timber production or other goals. Application of ecological forestry in conjunction with these options for riparian conservation areas could result in the retention of more forest within the outer zone of the riparian conservation area in matrix lands than estimated here. Retention aggregates, particularly the larger aggregates, could be located along fish-bearing streams (fig. 2). As a result, a portion of the outer zone managed for timber and ecological values could be assigned to retention patches, increasing the number of trees in the outer zone.

[6] Matrix prescription of the Northwest Forest Plan uses variable-retention harvest, although at a somewhat lower retention rate than recommended for ecological forestry by Franklin and Johnson (2012).

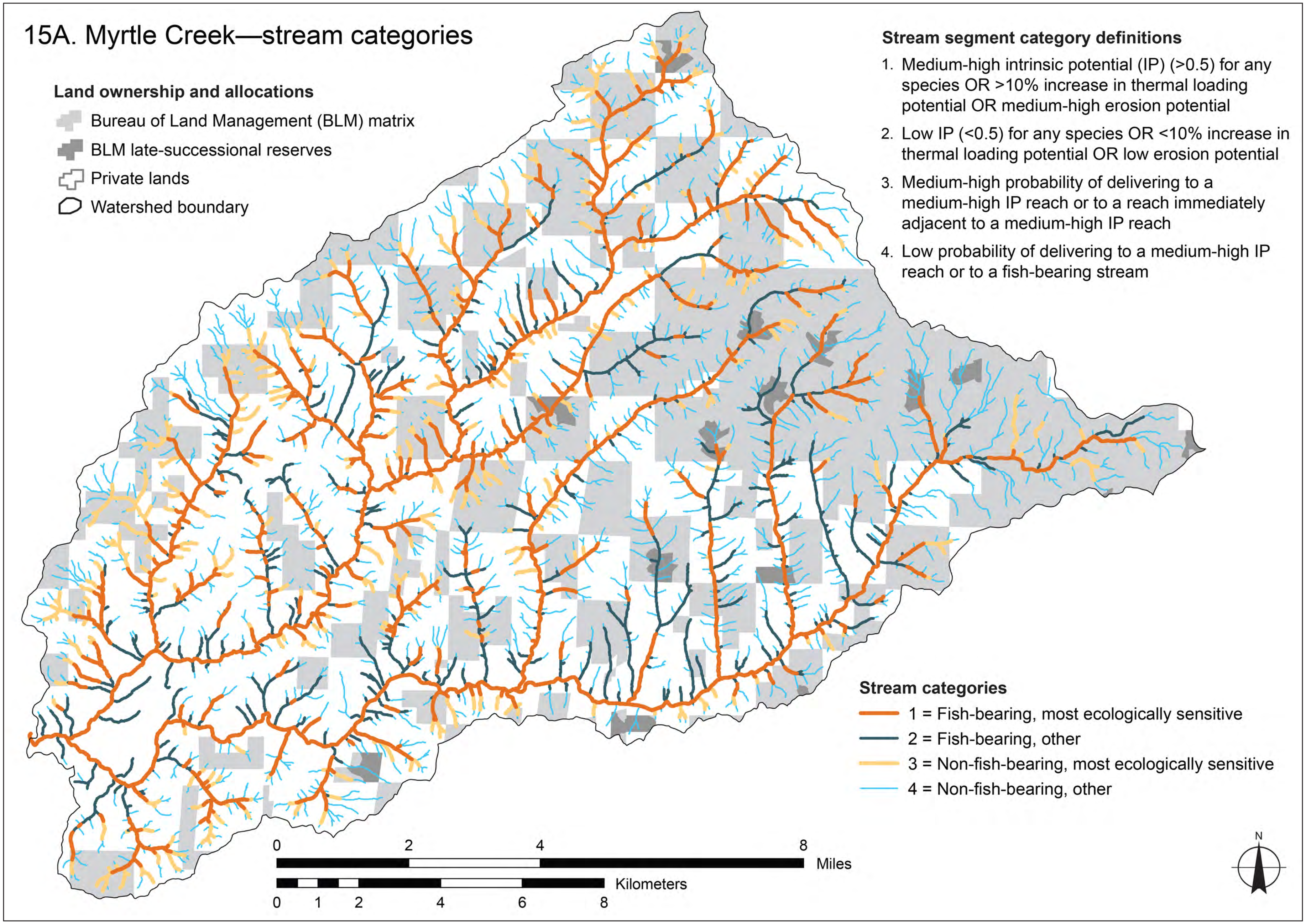
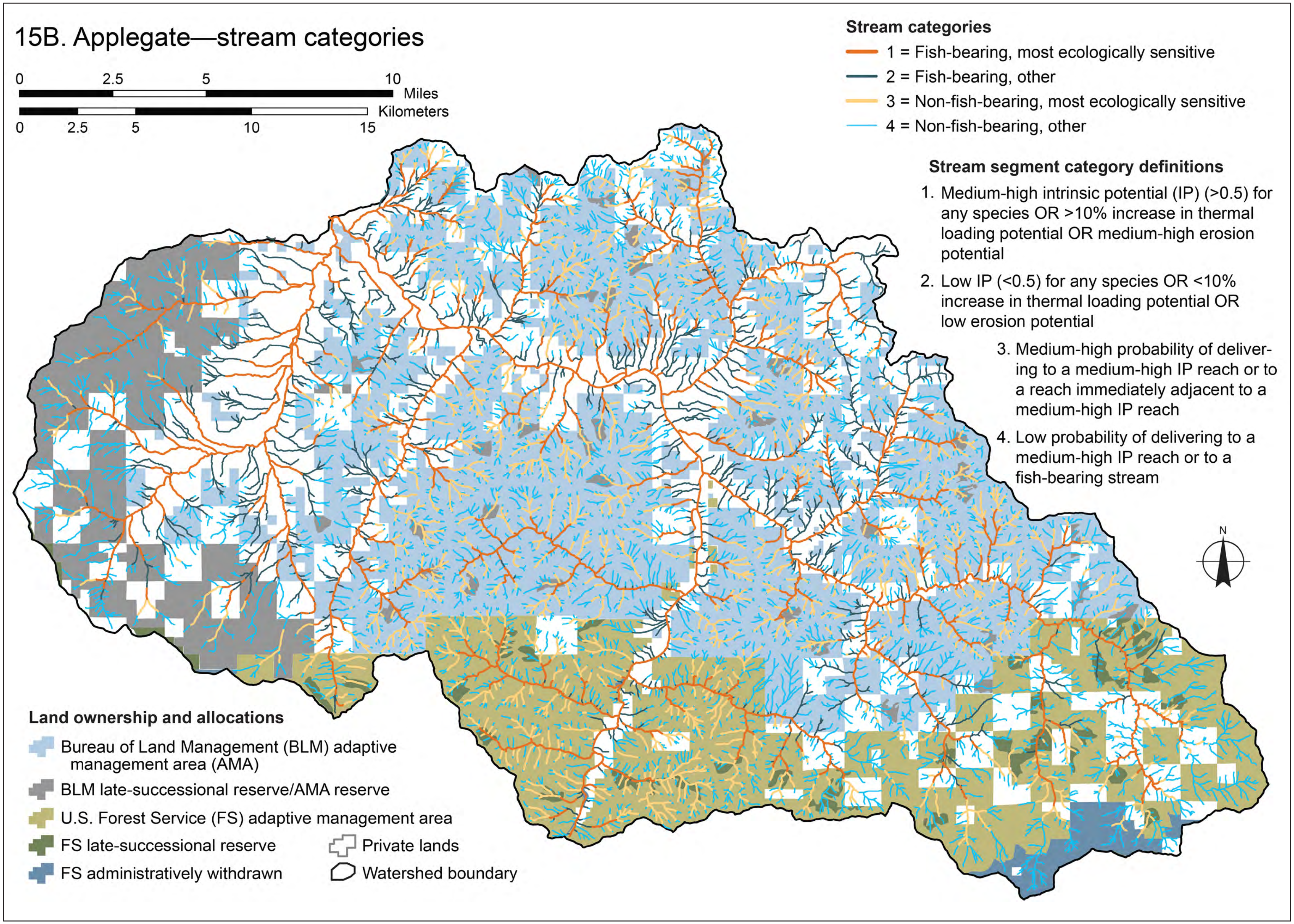


Figure 15—Streams classified into ecologically sensitive and other, fish-bearing and non-fish-bearing categories in the six study watersheds. (A) Myrtle Creek; (B) Applegate; (C) Coquille; (D) North Umpqua; (E) McKenzie; (F) Smith/Siuslaw.



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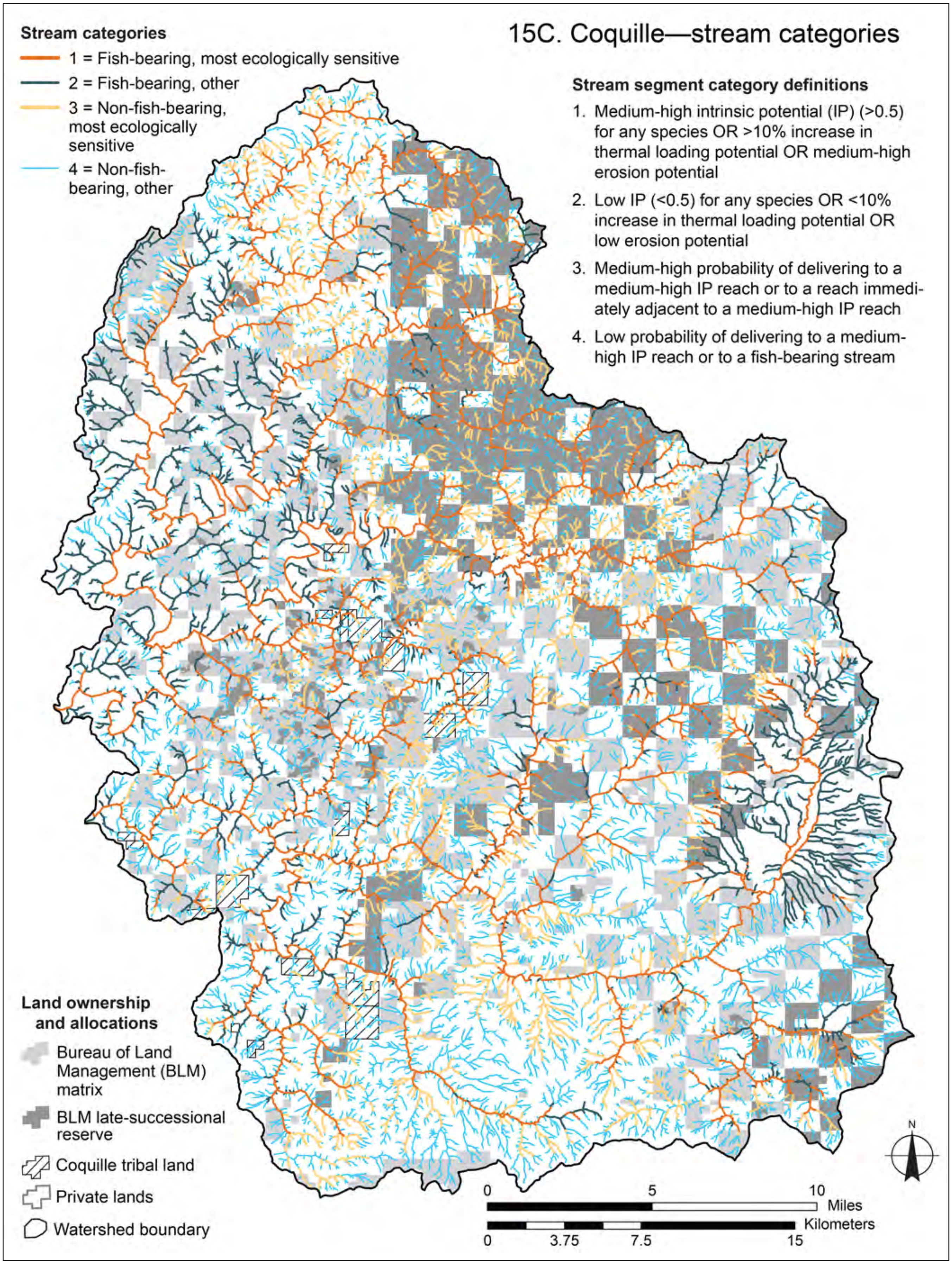

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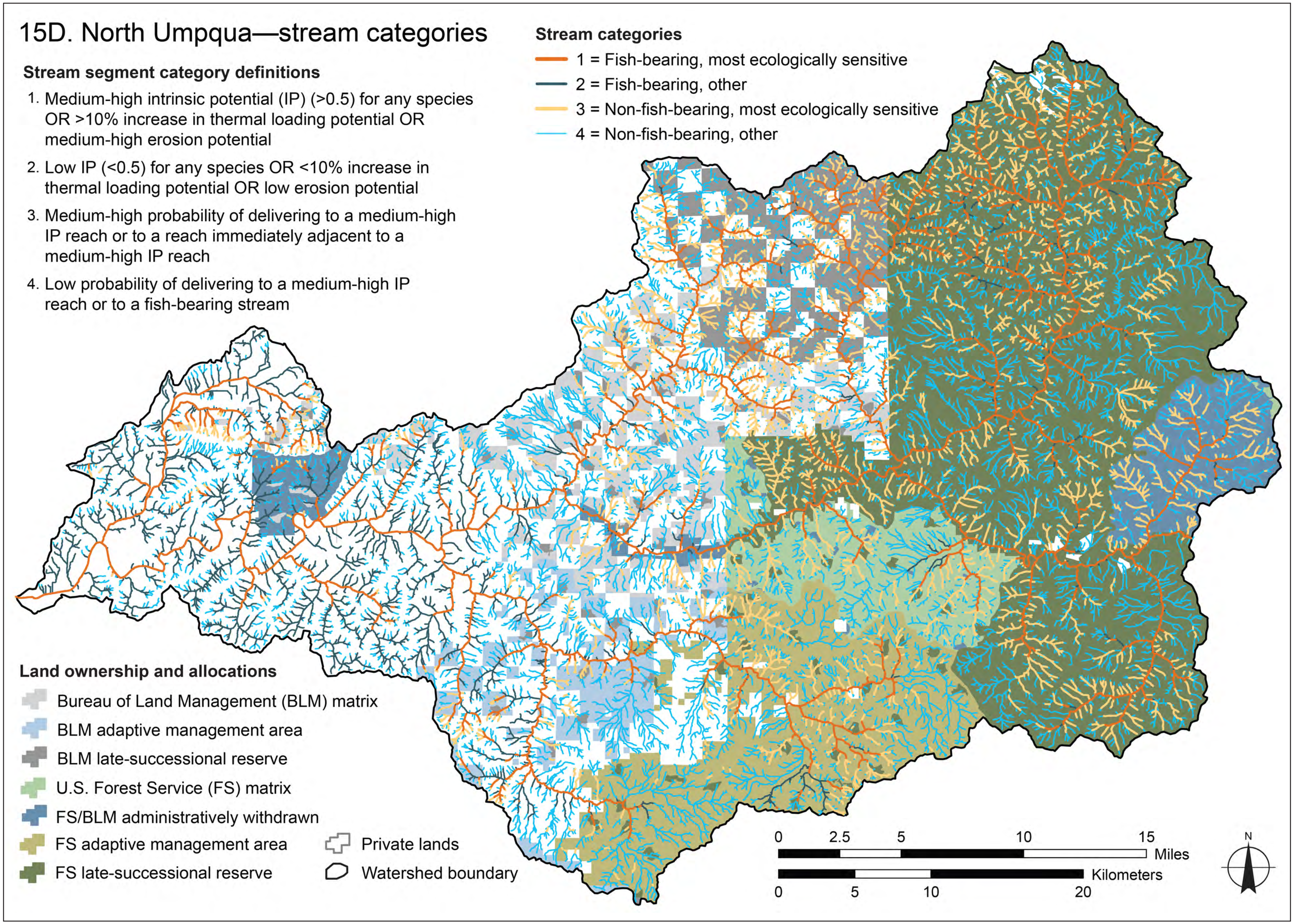

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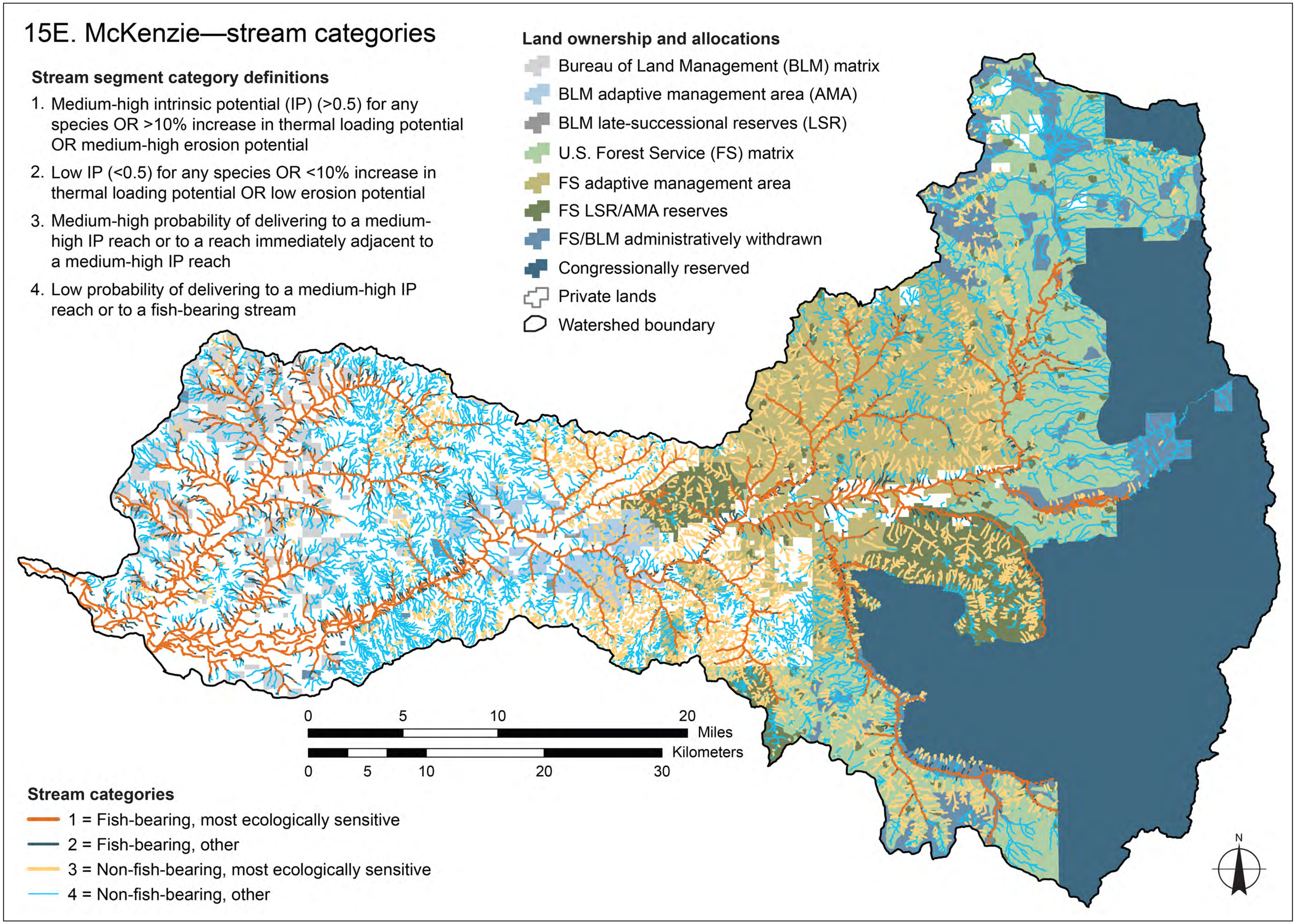

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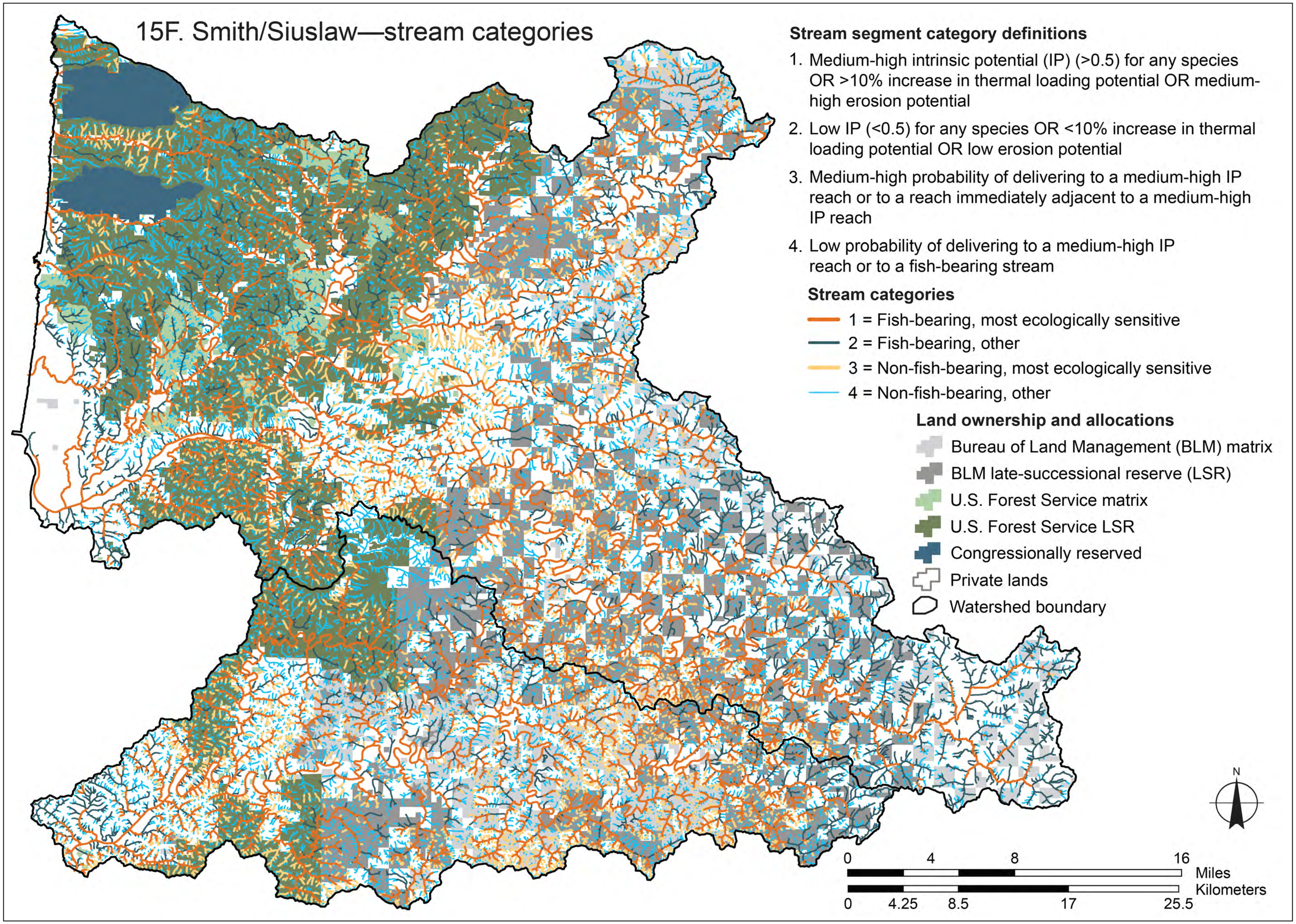

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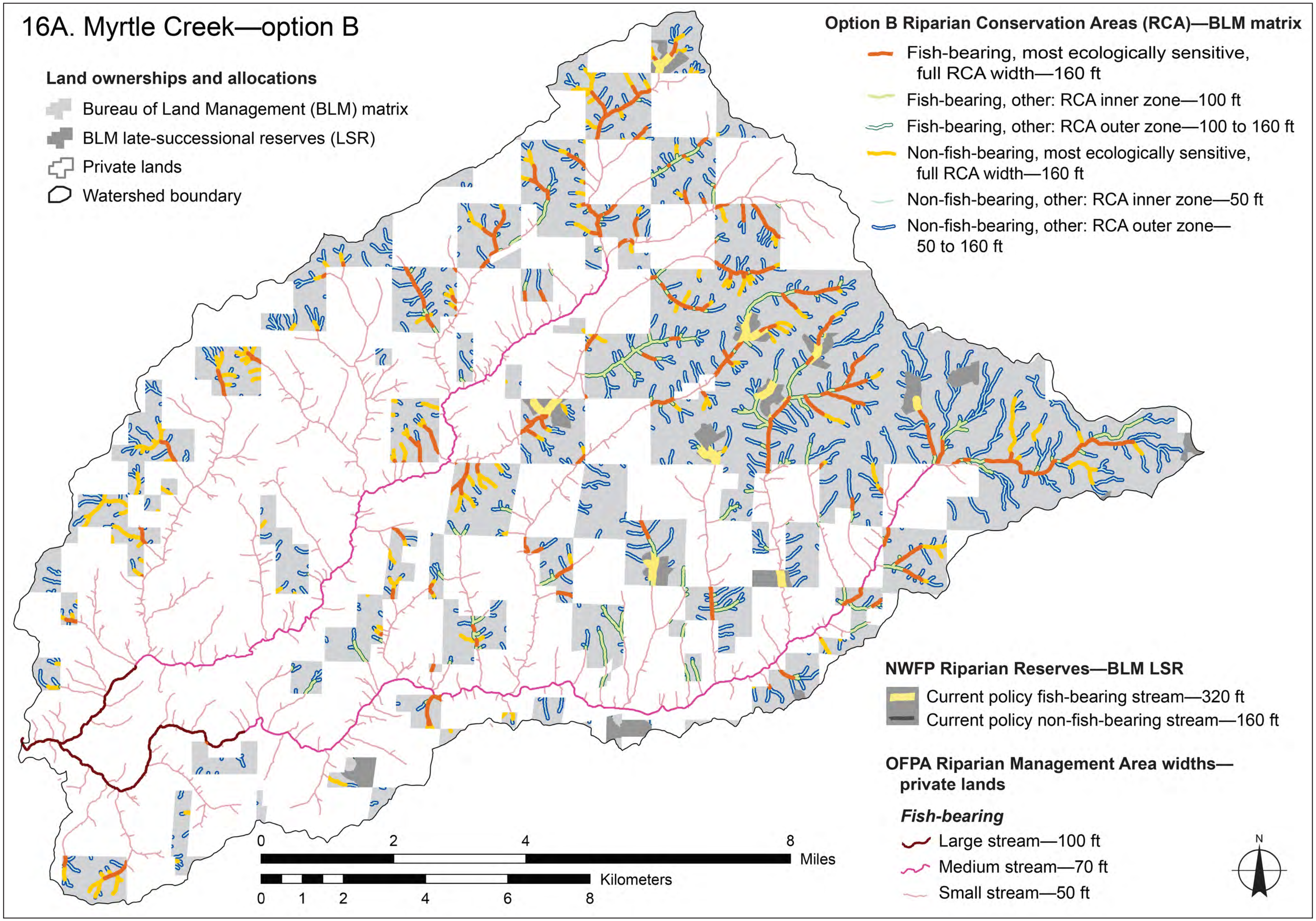
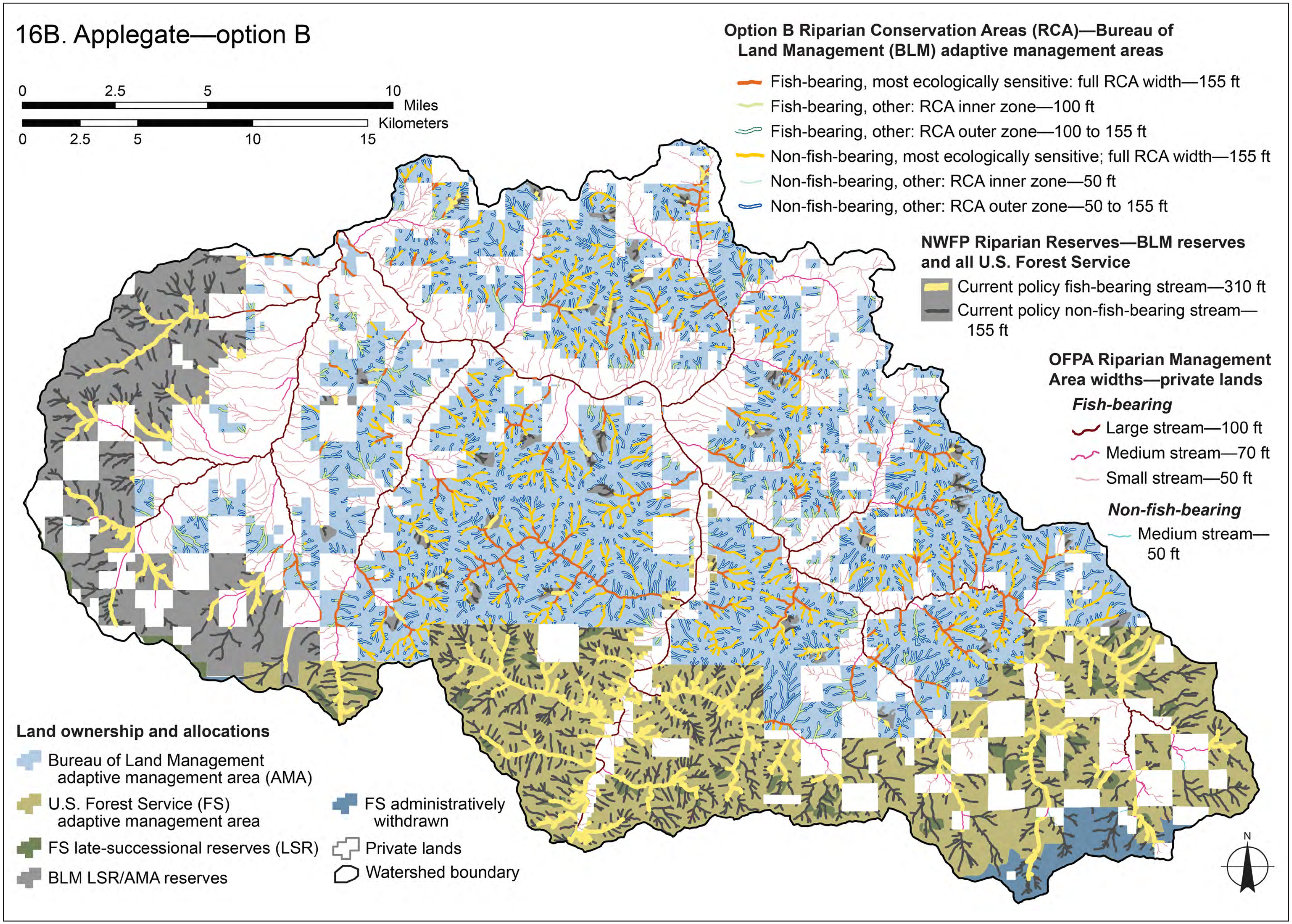


Figure 16—Simulation of option B riparian conservation area zones for the six study watersheds. (A) Myrtle Creek; (B) Applegate; (C) Coquille; (D) North Umpqua; (E) McKenzie; (F) Smith/Siuslaw.



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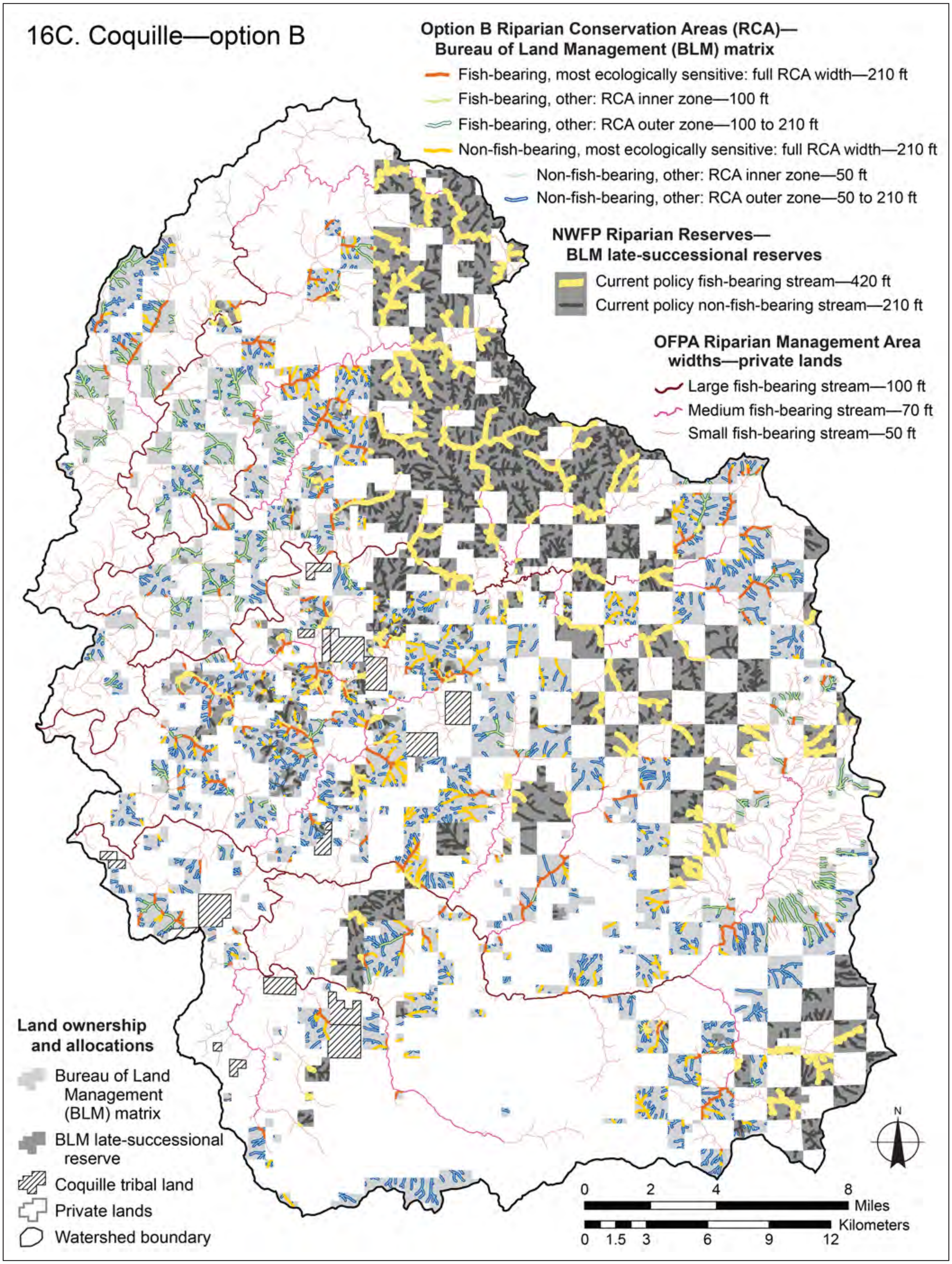

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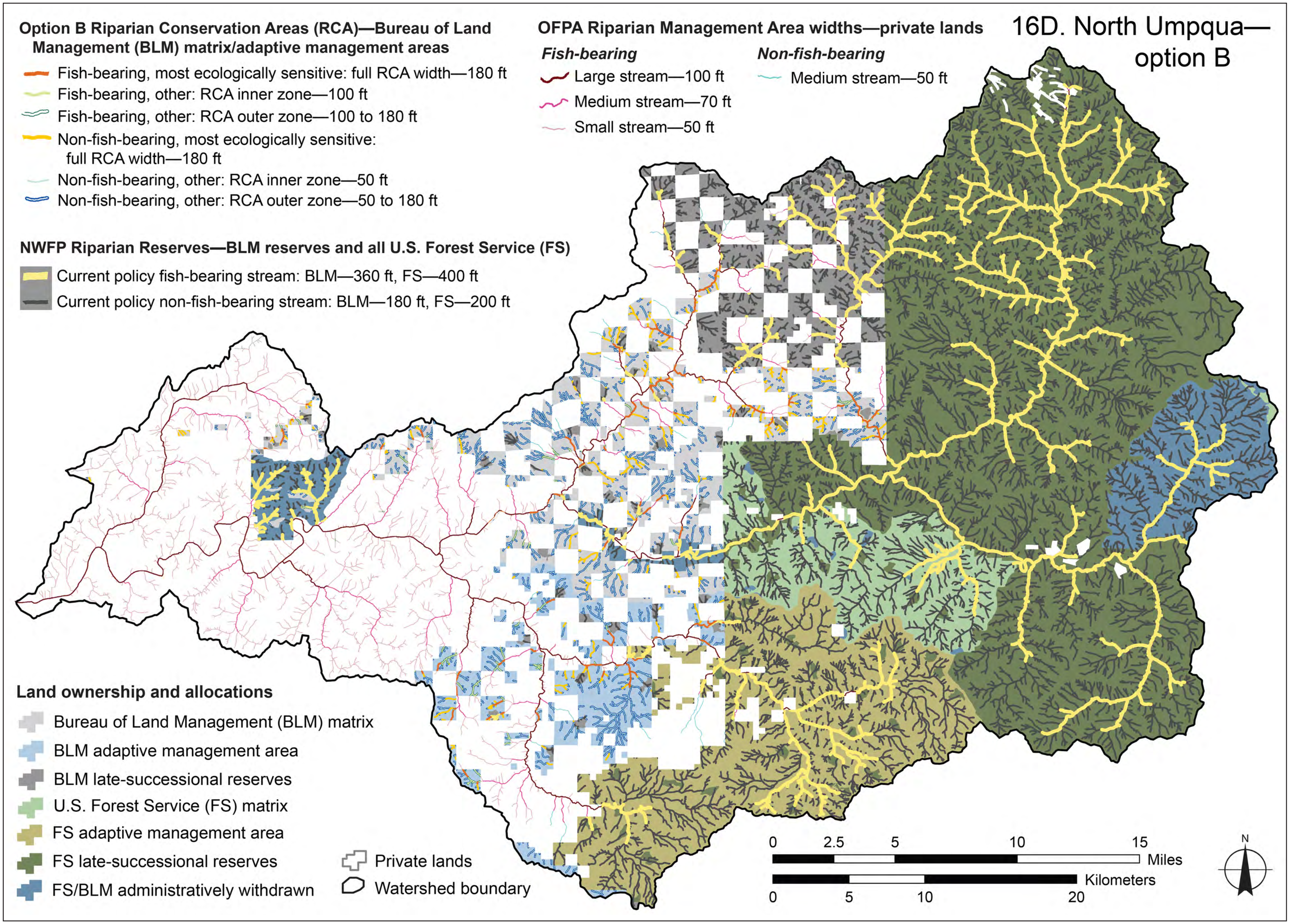

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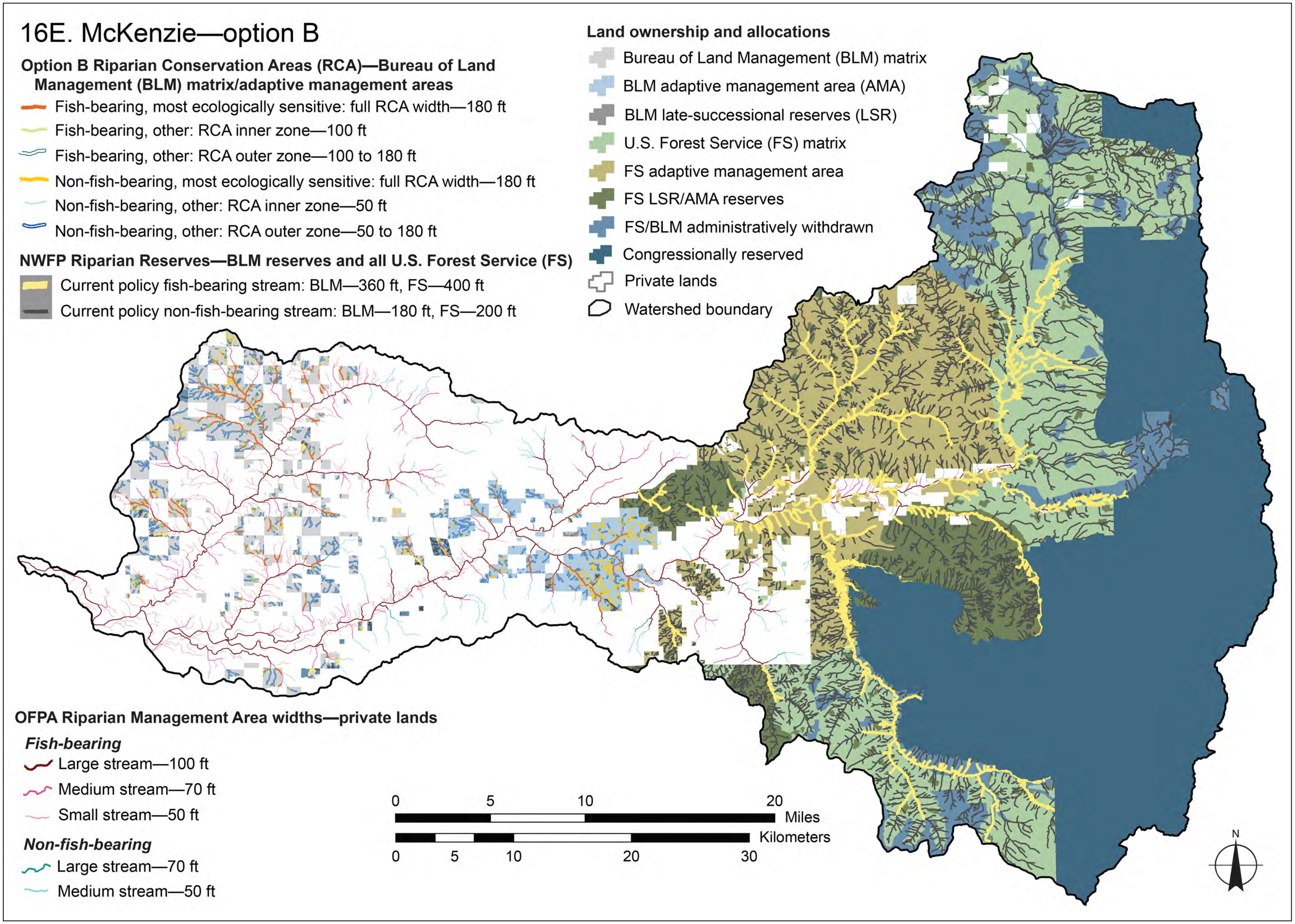

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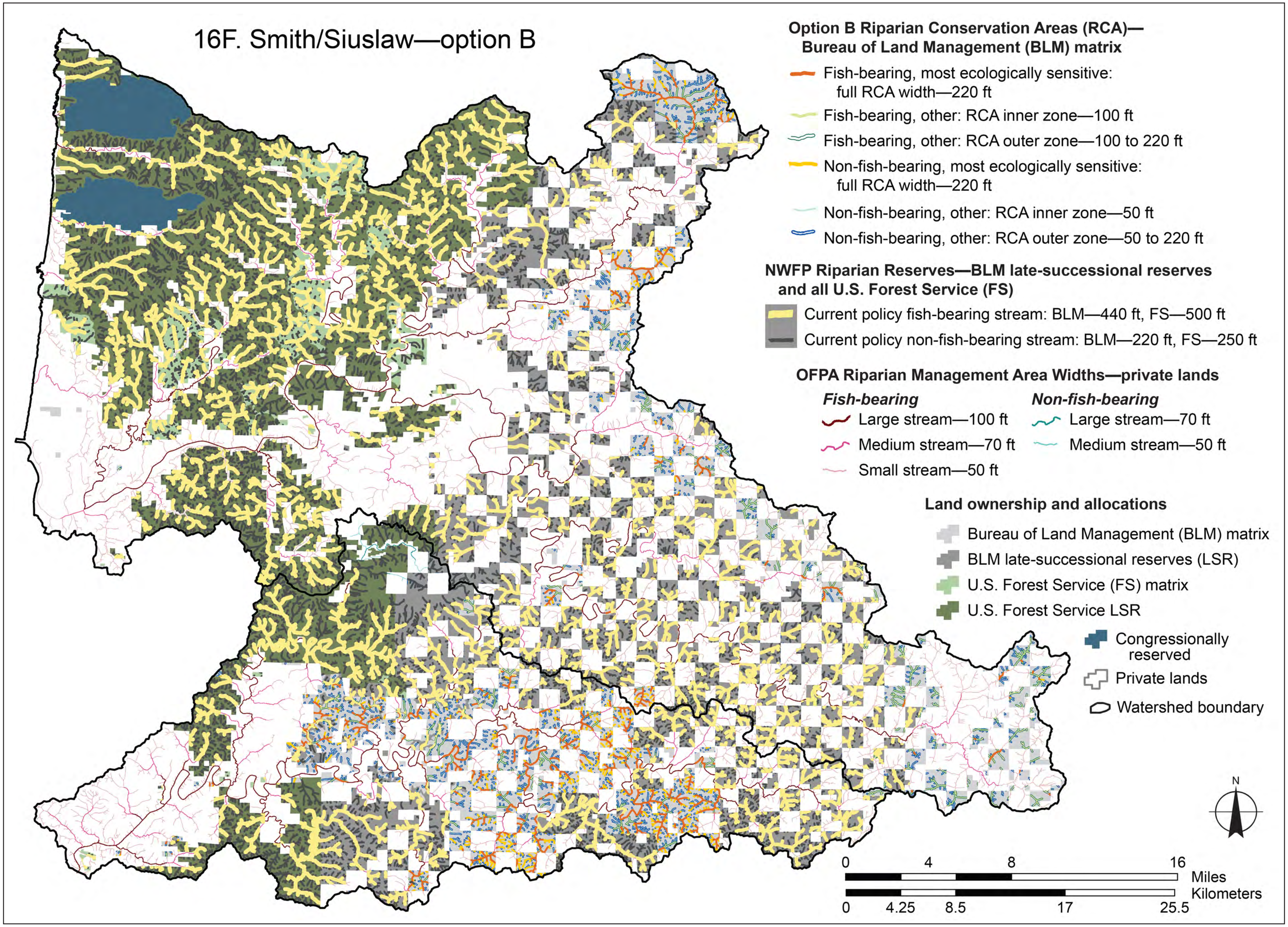

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Table 9—Percentage of fish-bearing and non-fish-bearing streams, by land ownership group, designated as "most ecologically sensitive" under potential option B in the six case-study watersheds in western Oregon

	Percent of stream network in ownership in "most ecologically sensitive" category								
	Fish-bearing streams			Non-fish-bearing streams			Total stream network		
Watershed	Federal	Nonfederal	Acreage-weighted average	Federal	Nonfederal	Acreage-weighted average	Federal	Nonfederal	Acreage-weighted average
Myrtle Creek	56	61	60	24	21	23	31	41	37
Applegate	74	53	68	32	19	28	39	37	39
Coquille	58	58	58	30	27	28	39	39	39
North Umpqua	77	61	74	30	25	29	37	34	36
McKenzie	69	65	67	36	24	32	42	35	40
Smith/Siuslaw	53	55	54	27	28	27	37	43	40
Acreage-weighted average	66	58	63	30	25	28	38	39	38

Table 10—Proportion of interim riparian reserves in matrix assigned to different management objectives in potential options A and B for six case-study watersheds on BLM lands in western Oregon

	Proportion of interim riparian reserves allocated among management objectives					
	Option A			Option B		
Watershed	ACS goals	Dual goals	Matrix goals	ACS goals	Dual goals	Matrix goals
Myrtle Creek	0.53	0.29	0.18	0.46	0.35	0.18
Applegate	0.53	0.35	0.13	0.54	0.34	0.13
Coquille	0.54	0.28	0.18	0.41	0.40	0.18
North Umpqua	0.53	0.36	0.11	0.45	0.44	0.11
McKenzie	0.53	0.26	0.21	0.45	0.34	0.21
Smith/Siuslaw	0.55	0.22	0.23	0.44	0.33	0.23
Weighted average	0.536	0.286	0.178	0.460	0.362	0.178

ACS = Aquatic Conservation Strategy.

Across all BLM lands in western Oregon—
The change in the proportional area in interim riparian reserves when the entire BLM landscape in western Oregon is considered is less than what occurs in matrix. For the No Action Alternative (Northwest Forest Plan), the BLM estimates (USDI BLM 2015, p. 29) a total acreage in western Oregon of 2,331,989 ac, divided between matrix (including interim riparian reserves) of 1,219,548 ac (52 percent) and late-successional and other reserves of 1,112,441 ac (48 percent).[7] A portion of matrix is also designated as critical habitat for the northern spotted owl, which

[7] The Eastside Management Area shown on page 29 of the *Western Oregon Draft RMP/EIS* (USDI BLM 2015) is excluded from the analysis because it lies outside the area of the Northwest Forest Plan.

Seventy six percent under Option A and 72 percent under Option B of interim riparian reserve on BLM lands in western Oregon remain devoted solely to achieving ACS goals.

reduces the forest available for harvest from what is estimated here. Matrix near the coast has the potential for being designated as additional critical habitat for the marbled murrelet as more sites are found, further reducing the area of matrix available for harvest. "Survey and Manage" requirements are also likely reduce the harvestable area of matrix. Thus, our estimate here of 52 percent matrix likely overestimates matrix area and underestimates reserve area.

Using this percentage of matrix and reserves (outside matrix), approximately 76 percent of the interim riparian reserve area on BLM western Oregon lands under option A and 72 percent under option B would remain devoted solely to the goals of the ACS (table 11). An additional 15 percent and 19 percent under options A and B, respectively, could contribute both to ACS goals and to matrix goals such as timber production. The overall reduction in the amount of interim riparian reserve area on the landscape would be 9 percent under both options (table 11).

Table 11—Weighted average percentage of interim riparian reserves (IRR) allocated among different management objectives from six case-study watersheds on Bureau of Land Management lands in western Oregon[a]

	Weighted average percentage of interim riparian reserves allocated among management objectives							
	Option A			Reclassified to allow matrix goals	Option B			Reclassified to allow matrix goals
	ACS goals	Dual goals	Matrix goals		ACS goals	Dual goals	Matrix goals	
Allocation of IRR in matrix	53.6	28.6	17.8		46.0	36.2	17.8	
Weighted by percentage of matrix (52 percent)	27.8	14.9	9.3		23.9	18.8	9.3	
Allocation of IRR in reserves outside matrix	100	0	0		100	0	0	
Weighted by percentage of reserves outside matrix (48 percent)	48	0	0		48	0	0	
Weighted average allocation of IRR	75.8	14.9	9.3	24.2	71.9	18.8	9.3	28.1

ACS = Aquatic Conservation Strategy.

[a]Assumes that Bureau of Land Management matrix and reserves (outside of matrix) in western Oregon have the same proportion in interim riparian reserves.

Rates and Intensities of Harvest in the Reclassified Interim Riparian Reserve

Reclassification of the interim riparian reserves affects the rate and type of harvest permitted in these areas. We estimate that approximately 24 to 28 percent of existing interim riparian reserves could potentially have timber production as a goal under the two options evaluated here (table 11). About one-third of that area would be returned to matrix prescriptions; the other two-thirds will retain its ACS goals but could have timber production as an added goal. Commercial thinning up to age 80 in moist forests and beyond 80 years (to reduce fuels) in dry forests is already allowed in the interim riparian reserves, although moderated by concerns about threatened fish stocks. We would expect thinning to continue, although the rate and intensity might increase somewhat, especially on the portion of the interim riparian reserves returned to matrix. A potentially more controversial change concerns the application of variable-retention harvest in moist forests, a silvicultural practice not permitted in interim riparian reserves. We will focus our discussion here on the potential magnitude of that change.

Variable-retention harvest followed by a few decades of diverse early-successional ecosystems (figs. 2 and 3) would emphasize the provision of habitat for early-seral species, a different goal than attempting to create diversity in existing stands and speeding development of late-successional forests. Also, variable-retention harvest would provide more harvest volume per acre than thinning, and would change the appearance of the forest more dramatically.

We would expect that the outer portions of the interim riparian reserves that could be available for timber harvest under options A or B would be harvested at about the same rate as the uplands. The BLM estimated that implementation of the No Action alternative (the NWFP) would result in an average amount of variable-retention harvest of approximately 43,932 ac per decade for the first two decades in matrix areas (USDI BLM 2015, p. 277). Across an estimated 691,998 ac of matrix lands (USDI BLM 2015, p. 29), approximately 6.3 percent of the matrix would be harvested per decade. Using our watershed case studies and estimates of the distribution of interim riparian reserves between matrix and late-successional and other reserves, we estimate that 24 to 28 percent of the interim riparian reserve area across the landscape would be reclassified to allow timber production as a management goal under options A and B, respectively (table 11). With a 6.3-percent variable-retention harvest rate per decade, 3 to 4 percent of the total interim riparian reserve area could receive a variable-retention harvest over the first two decades.[8]

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[8] Calculated as 24.1 × 6.3 × 2 = 3.0 percent for option A and 28.1 × 6.3 × 2 = 3.5 percent for option B.

In some watersheds, private lands contain the majority of "most ecologically sensitive" streams.

Distribution of Stream Classes Between Landowner Groups

The relative proportion of "most ecologically sensitive" streams varies between federal and nonfederal (private) lands,[9] as well as by watershed, and both ownership types contain significant numbers of these streams (table 9). When private lands lie in the lower portions of the watershed, such as in Myrtle Creek, a greater proportion of "most ecologically sensitive" fish-bearing streams are found on private lands (table 9; fig. 12A; fig. 17). When federal and private lands are more intermingled in the lowlands, as in the Coquille and Smith/Siuslaw (table 9; figs. 12B and 12F; fig. 17), landowners share more equally in the proportion of "most ecologically sensitive" fish-bearing streams.

Potential Impacts on Terrestrial Biodiversity

Many terrestrial species use the area near streams for at least part of their lives, as acknowledged in FEMAT (1993) and the documents associated with the Northwest Forest Plan (USDA and USDI 1994, RIEC and IAC 1996). These documents discuss the "size" of the riparian reserves as being important for some mammals and amphibians, and the FEMAT summary (p. II-31) describes riparian reserves serving as dispersal habitat for the northern spotted owl. There is also reference to riparian reserves being important for connecting late-successional reserves for organisms with limited dispersal capabilities (e.g., fungi, plants, flightless insects, amphibians, mollusks) (p. IV-187), and a paragraph in the aquatic section (p. V-34) that describes the importance of riparian reserves as travel and dispersal corridors for terrestrial animals and plants. Thus, potential changes to riparian reserves need to consider the effects on these organisms.

We surmise that, in general, effects on terrestrial species of adopting either option A or option B will be minimal for the following reasons:

1. In the development of the Northwest Forest Plan, much of the evaluation of effects of different management options on species centered on harvest of mature and old-growth stands (FEMAT 1993). A number of factors make harvest of these stands unlikely to any significant degree, including recommendations for their retention in the new Northern Spotted Owl Recovery Plan (USFWS 2011), prescriptions associated with ecological forestry (box 1), and the approach herein that limits harvest within one tree-height of streams to stands currently less than or equal to 80 years of age.

[9] "Private lands," as defined in our study, include Coquille tribal lands in the Coquille watershed.

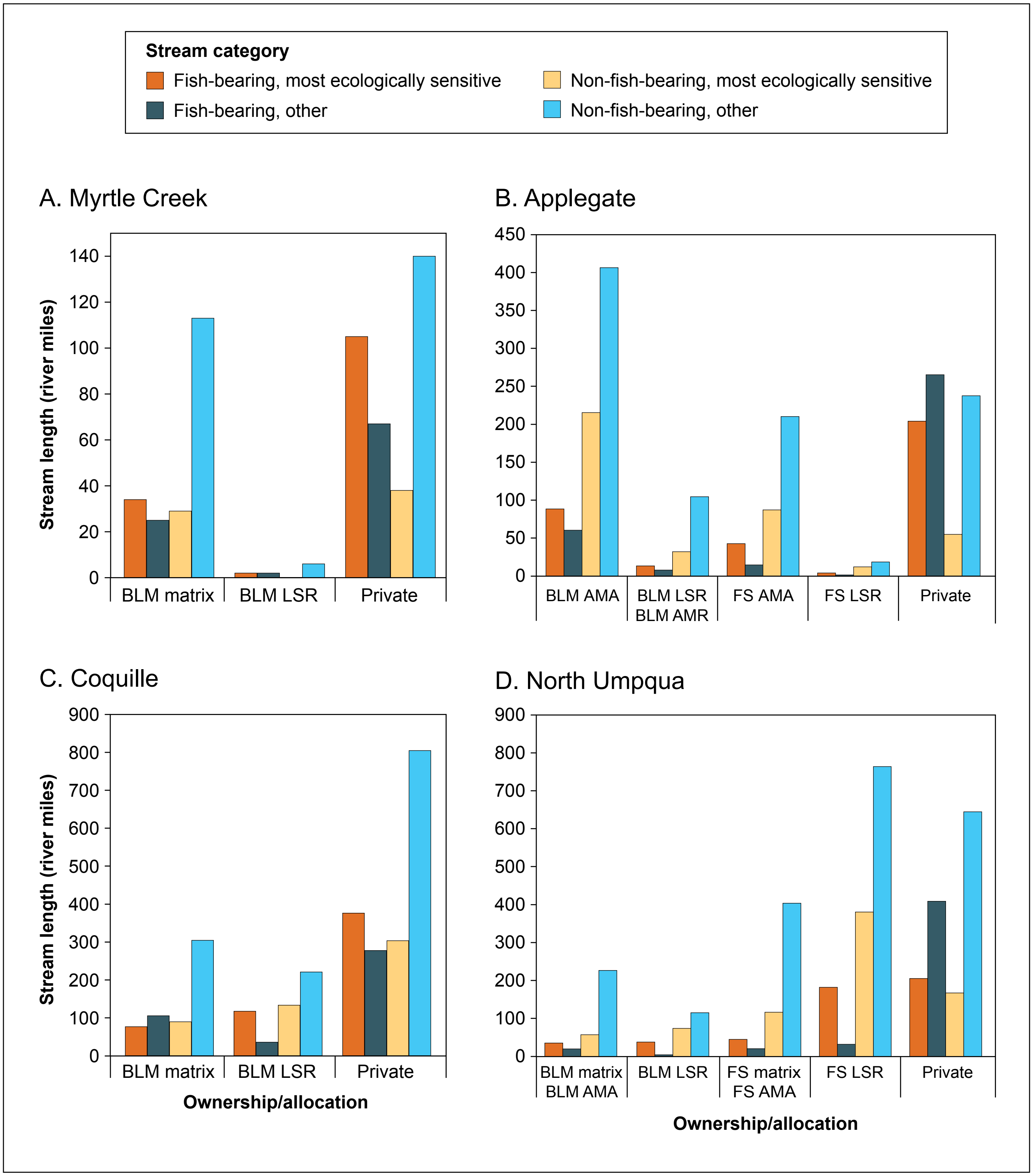

Figure 17—Proportion of fish-bearing and non-fish-bearing stream length categorized as most ecologically sensitive and other in the six study watersheds, by ownership. Note that a large proportion of the most ecologically sensitive fish-bearing streams are on private lands. (A) Myrtle Creek; (B) Applegate; (C) Coquille; (D) North Umpqua; (E) McKenzie; (F) Smith/Siuslaw.

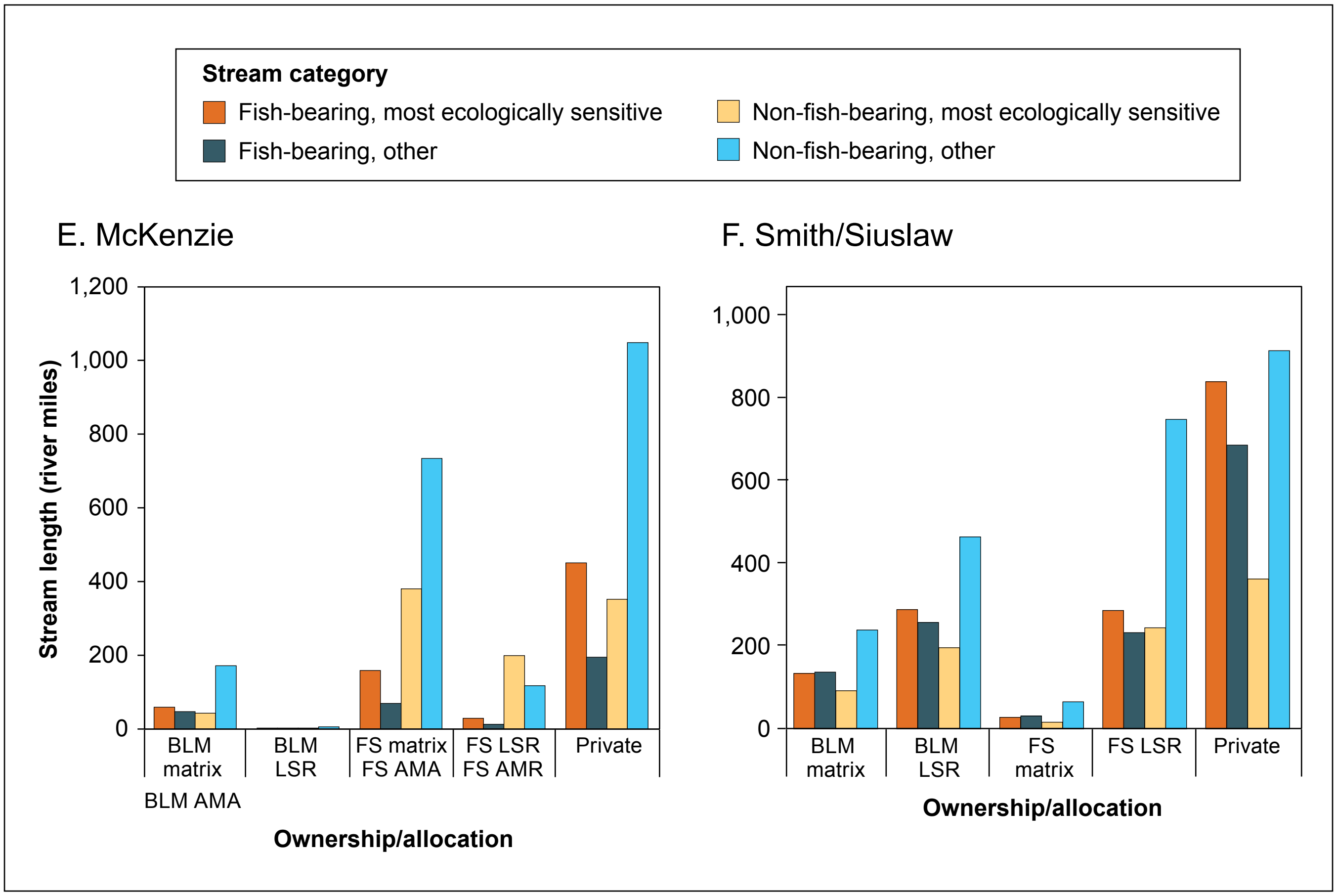

Figure 17—Continued.

2. Most of the forest area in the Northwest Forest Plan's interim riparian reserves (within two site-potential tree-heights of fish-bearing streams or one site-potential tree-height of non-fish-bearing streams) would be unaffected by adoption of options A or B.

3. Use of ecological forestry in the riparian conservation areas (one tree-height along both fish-bearing and non-fish-bearing streams under options A and B) includes aggregate retention patches that can be placed to aid movement of organisms with low dispersal capabilities, including mollusks, mosses, fungi, and lichens (Olson et al. 2007), and can increase the width of the protected area along the stream beyond what is specified in the option.

4. A relatively low rate of regeneration harvest in the interim riparian reserves would likely occur.

5. Although the forest near streams on federal lands has been highlighted as a potential movement corridor for some species, the fragmented (often checkerboard) nature of the BLM's western Oregon forests makes it difficult to maintain continuous streamside forest across the landscape no matter what management policies are chosen for federal lands. On the other hand, connectivity along diagonals of the checkerboard ownership has been proposed (Olson and Burnett 2013, Olson and Kluber 2014) and warrants assessment.

Research Implications

Criteria used to design the riparian conservation area for options A and B rely heavily on science derived since development of the NWFP, including empirical studies of the effects of riparian buffers and models of landscape habitat suitability or processes that may affect aquatic systems. Research needs include further development of these relevant science themes, as well as monitoring the effects of option implementation on specific elements named in ACS objectives. Research on and monitoring of option implementation can lead to informed adaptive management to improve the efficacy of riparian management for aquatic-riparian restoration. Some key research areas include:

Monitoring the effects of option implementation is imperative.

1. Assessing the effects of riparian conservation area implementation on ACS attributes at the spatial scale of whole watersheds. The ACS attributes of interest include instream habitat and water quality, along with aquatic, riparian, and terrestrial species of concern, including abundance, habitat quality assessment, habitat use, and dispersal. Specific questions include:
    - What are the differential effects of riparian conservation areas under option A or B, with ecological forestry implemented upslope?
    - Are there cumulative effects if implementation is clustered among adjacent watersheds in a small area of the NWFP?
2. Validating landscape models with field-derived data for down-wood recruitment including tree-tipping, thermal loading, and landslide potential. Specifically:
    - Do riparian conservation areas under option A or B with ecological forestry implemented upslope change any assumptions for dynamics of wood recruitment (e.g., is blowdown more likely?), thermal loading, or sedimentation processes?
    - What site-specific contexts may need consideration for model accuracy?
    - Is a no-entry zone in the portion of the riparian conservation area specified for ACS goals necessary, for example to reduce erosion potential?

- What temporal considerations are needed for tree-tipping to maximize efficacy of large wood recruitment to streams?

3. Assessment of efficient placement of aggregated patches of green-tree retention. For example:
   - What stream, riparian, or upland ecosystem services can be addressed by patch placement?
   - Can patches aid local distribution of sensitive species or habitat attributes?

Conclusions

It was expected that the boundaries of the interim riparian reserves of the Northwest Forest Plan could and would be modified as a result of watershed analysis. However, as described previously, this has not happened for a number of reasons and, as a result, relatively little management has occurred in the reserves, especially within one tree-height of streams (Reeves 2006). To help provide understanding of recent scientific information and analysis tools in a management context, we did an initial ecological evaluation of two potential options that reduce the area of interim riparian reserves needed to meet the goals of the ACS of the Northwest Forest Plan, while providing opportunities to achieve other management goals, such as increased timber harvest and associated revenue from a portion of these lands. These options fall within the bounds of what was expected by the developers of the ACS (FEMAT 1993) and the ROD (USDA and USDI 1994), and are based on science produced since the ACS was developed.

Aquatic Conservation Strategy goals should continue to be met under either potential option.

Based on our summary of new science and evaluation of these potential options, the ACS should continue to be met under either potential option. Both options employ tree-tipping to ensure that thinning inside riparian reserves does not reduce the amount of wood falling into the stream. This technique should increase the compatibility of timber harvest or thinning for restoration and aquatic goals throughout the area of the Northwest Forest Plan. We also expect that the portion of the riparian conservation areas managed solely for the goals of the ACS in matrix in each option is sufficient to maintain water temperatures and microclimate within ecologically acceptable ranges and minimize the potential for excess erosion. These options are novel ideas that could be considered for the BLM lands, and are unlikely to compromise the goals of the ACS. They should be viewed as working hypotheses, much like the interim riparian reserves. Any implementation and subsequent evaluation of these or similar options would benefit from an adaptive management context to assess their effectiveness in meeting ACS goals and for continual improvement as additional information becomes available over time.

Placement of a stream reach in the "most ecologically sensitive" category is a function of achieving a certain threshold value for any one of our three criteria for fish-bearing streams (intrinsic potential, temperature, or susceptibility to erosion) or one criterion for non-fish-bearing streams (susceptibility to debris flows) (table 3). We justified our threshold values earlier in this report, but initial sensitivity analysis suggests that the choice of other threshold values can affect, somewhat, the segments classified as most ecologically sensitive. Policymakers and managers may wish to set the thresholds differently, however. For example, IP values of >0.7 could be used—the value for "high" IP areas (Burnett et al. 2007). This threshold would identify stream segments with the greatest potential to contribute to conservation and the recovery of ESA-listed fish species. Additionally, the threshold for inclusion of a non-fish-bearing stream based on the potential of debris flows to deliver materials to fish-bearing streams could be adjusted from the top 25 percent level that we used. Burnett and Miller (2007) suggested that greater conservation benefits accrue with a greater proportion of streams with high debris-flow potential being devoted to conservation than to timber harvest. However, the use of tree-tipping as one of the management actions along these streams would help ensure that wood recruitment into them continues, and that wood is available for delivery to fish-bearing streams from all headwater streams.

Our analysis also suggests that it could be difficult to rely solely on federal lands to recover and conserve freshwater habitat for native salmonids, including the ESA-listed coho salmon in western Oregon, given the significant proportion (approximately half [table 9]) of "most ecologically sensitive" stream segments that are found on nonfederal lands. The type of analysis done here using NetMap (Benda et al. 2007) can potentially be useful to watershed councils and others in identifying where to most effectively direct resources aimed at the protection and restoration of aquatic ecosystems across the landscape.

Although climate change was not considered in the development of the ACS, the potential options considered here should provide conditions for organisms to meet the challenges presented by a warming planet. Freshwater resources, including those in the NWFP area, are among the most vulnerable resources to climate changes (Bates et al. 2008). One of most immediate and pronounced impacts of climate change will be increased air temperatures (Mote et al. 2003). Water temperatures are projected to increase as a result (Isaak et al. 2012), although the extent of change will vary widely (Arismendi et al. 2012). Recent research (Cristea and Burges 2010, Lawrence et al. 2014, Perry et al. 2015) suggests that adequately sized and stocked riparian areas can offset the potential effects of climate change on water temperatures.

Our analysis focused on how different-sized buffers along fish-bearing streams in matrix would change the amount of solar radiation (a surrogate for stream temperature) that could reach the water surface. The one site-potential tree-height buffer on fish-bearing streams in option A should be sufficient to prevent any increases in water temperature. In option B, susceptibility to increases in the amount of solar radiation reaching the stream was one of the ecological sensitivity criteria: we limited buffer reductions on fish-bearing streams on matrix lands to those that showed less than a 10-percent increase in the estimated amount of solar radiation that could reach the stream on the hottest day of the year. This is a conservative threshold for changes that could affect water temperature, thus minimizing the potential for adverse increases in water temperature. Currently, about two-thirds of fish-bearing streams in matrix on federal lands across our case-study watersheds would retain a riparian conservation area of one site-potential tree-height. As a result, the riparian conservation areas should be sufficient to prevent, and potentially offset, increases in water temperature related to climate change in many systems.

Winter precipitation and flows (Mote et al. 2003, Tague and Grant 2009) are also likely to increase as a consequence of climate change, which will in turn increase landslides and debris flows. The potential options focus on increasing the occurrence of large trees by limiting management to stands ≤80 years of age, using tree-tipping into streams, retaining larger riparian conservation areas on non-fish-bearing streams with the high probability to deliver wood and sediment to fish-bearing streams, and restricting activities in the more erosive portions of the stream network. These provisions should help sustain key ecological processes that create and maintain suitable habitat for fish and other aquatic and riparian-dependent species through time.

Assuming that the other components of the ACS, including key watersheds, watershed analysis, monitoring, and standards and guidelines would not change and that interim riparian reserves in LSRs and other reserved and withdrawn lands would remain in place, the options evaluated here provide examples of potential ways to implement the ACS while meeting other management goals and the challenges of climate change. As estimated above (table 11), 72 to 76 percent of the area in NWFP interim riparian reserves in the BLM's western Oregon lands would still be devoted solely to achieving the goals of the ACS, depending on which option was chosen. Therefore, we assess the potential for these options to reverse the progress of the ACS to date or to retard its continued achievement of the ACS goals as minimal. However, as with the interim riparian reserves, such options should be not be viewed as immutable and, therefore, implementation and evaluation in an adaptive management context (Stankey et al. 2005) would be prudent to enable a response and adjustments to unforeseen effects in a timely manner.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters (cm)
Feet (ft)	0.305	Meters (m)
Miles (mi)	1.609	Kilometers (km)
Acres (ac)	0.405	Hectares (ha)
Miles/1,000 acres	3.9728	Kilometers/1000 ha
Trees per acre	2.47	Trees per hectare
Degrees Fahrenheit	0.56 (°F – 32)	Degrees Celsius

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