Chapter 6.2—Forested Riparian Areas

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Summary

Riparian areas are typically highly productive areas that sustain important socioecological benefits, including the capacity to modulate effects of watershed disturbances on aquatic systems. Recent studies have shown that fire behavior in riparian areas varies with landscape attributes. Smaller, headwater riparian areas often burn similarly to adjacent uplands, whereas riparian areas next to larger streams (4th order and higher) often burn less frequently and less severely because of moister microclimates, and therefore can serve as fire breaks within a landscape. However, other riparian areas may accumulate fuels rapidly owing to their high productivity, and during dry fire seasons they can serve as wicks that carry high-intensity fire through a landscape. These localized relationships with fire suggest that treatment strategies for riparian areas should be customized and likely would differ. However, riparian areas that are vulnerable to uncharacteristically high-severity fire may benefit from being included in upland treatments to render them and their associated landscapes more resilient to wildfire. Furthermore, treatments that reduce tree density and increase light may have positive effects on understory plant diversity and aquatic productivity in some riparian areas, including those with aspen. Studies on prescribed fire in Sierra Nevada riparian areas have found relatively benign impacts. However, information about the effects of both mechanical treatments and fire treatments is still relatively limited, which suggests a need for experimental treatments. Overall, an adaptive management strategy based upon active management within some riparian areas may promote resilience better than a broad hands-off approach.

Introduction

Riparian areas are important transition zones between terrestrial and aquatic ecosystems that can modulate effects from the watershed and provide valuable socioecological benefits. This chapter uses the term **riparian area** broadly to describe the "stream-riparian corridor," which consists of the stream channel,

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adjacent floodplains, and the transitional upland fringe, as defined by Dwire et al. (2010).[3] When Dwire et al. (2010) synthesized the state of knowledge about the potential impacts of streamside and upland fuels management on riparian areas, they found that most information was derived from studies on the effects of forest harvest or wildland fire. Although research about fire history strongly suggests a need for treatments within many riparian areas, limited information about the effects and effectiveness of mechanical treatments and prescribed fire treatments currently limits guidance for managing these valuable riparian ecosystems. As a consequence, these systems continue to present an important opportunity for research on riparian responses to treatments as well as to fires of different severities.

Fire is an agent of renewal and redistribution in riparian and aquatic systems within large landscapes over long periods.

Luce et al. (2012) provided a timely and relevant synthesis of information concerning strategies for promoting resilience in riparian and aquatic ecosystems in the face of wildfire and climate change. They emphasized several important functions of riparian areas, including provision of shade, inputs of large woody debris and allochthonous organic matter, streamside habitat, and bank stability. One of their central themes is the role of fire as an agent of renewal and redistribution in riparian and aquatic systems within large landscapes over long periods.

Fire History and Behavior in Riparian Areas

Riparian plant communities evolved within the ecological context of regional fire regimes. A broader review of fire and fuels in the synthesis area is provided in chapter 4.1, "Fire and Fuels." Luce et al. (2012) presented four generalized scenarios of fire behavior and effects in riparian areas:

- Riparian areas burn like adjacent uplands because of similar vegetation and topography;
- Riparian areas burn less frequently or less severely than adjacent uplands because of soil and terrain that maintain moist microclimates;
- Riparian areas serve as fire breaks, particularly on large, perennial streams;
- Riparian areas burn more frequently or more severely than adjacent uplands where fuel loads are higher along low-order streams in steep terrain with south-facing aspects.

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[3] Riparian areas have been defined in the planning rule by the Forest Service as "three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at variable widths" (Office of the Federal Register 2012: 1411).

Research findings provide support for these different scenarios. Data from perennial streams in the Klamath Mountains suggest that fire return intervals (FRIs), and possibly fire behavior, are more variable within riparian zones than in adjacent uplands. Skinner (2003) found that median FRIs were generally twice as long on riparian sites than on neighboring uplands, but found no substantial differences in the range of FRIs between the two landscape types. Taylor and Skinner

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Figure 1— (A) An intermittent stream and (B) a perennial stream (Hull Creek), both on the Stanislaus National Forest, demonstrate some of the diversity in riparian habitats within the synthesis area.

(2003) found that areas with similar timing of fires were several hundred hectares in size and bounded by topographic features (e.g., ridgetops, aspect changes, riparian zones, and lithologic units) that affect fuel structure, fuel moisture, and fire spread. However in very dry years, fires would spread across such boundaries. Thus, by affecting fire spread, riparian areas contribute to the structure and dynamics of upland forest landscapes (Skinner 2003, Skinner et al. 2006, Taylor and Skinner 2003). This is an example of the linkage between aquatic and terrestrial ecosystems.

Using remotely sensed Burned Area Reflectance Classifications from four fires in the Intermountain Region, Fisk et al. (2004) found that riparian areas burned less severely than upland areas in general, but that lower order streams burned more like uplands, and that slope and aspect were more watershed-specific factors. Luce et al. (2012) summarized the average FRI for riparian areas across five studies in dry forests as 12 to 36 years. That value is very similar to the return interval of 10 to 31 years for uplands in the same studies. However, they found that the average FRI in mesic forest types, based upon two studies from the Klamath Mountains in California and the Cascade Range in Oregon, is much longer: 26 to 41 years in riparian versus 17 to 25 years in associated uplands. Two of the studies included in the synthesis by Luce et al. (2012) are discussed in greater detail below.

Research in the Sierra Nevada has indicated that riparian forests have higher fuel loads than adjacent uplands, and that on smaller and more incised streams, forested riparian areas have fire histories similar to adjacent uplands.

First, research in the Sierra Nevada has indicated that riparian forests have higher fuel loads than adjacent uplands, and that on smaller and more incised streams, forested riparian areas have fire histories similar to adjacent uplands (Van de Water and North 2010, 2011). Conducted at 36 sites in the northern Sierra Nevada (Lassen National Forest, Onion Creek Experimental Forest, and Lake Tahoe Basin), these studies developed dendrochronological fire records in adjacent riparian and upland areas across a variety of forest and stream conditions. They sampled first- through fourth-order streams, with a particular focus on first- and second-order streams. Riparian and upland FRIs were significantly different in only one quarter of the sites they sampled. They found that the historical seasonality of fire did not differ between riparian and upland areas; in both, fires typically occurred in late summer to early fall. Riparian FRIs ranged from 8.4 to 42.3 years. Fire return intervals were shorter in forests with a higher proportion (>23 percent) of pine species, sites east of the Sierra Nevada crest, lower elevation sites (<1944 m), and riparian zones bordering narrower, more incised streams (width/depth ratio <6.2).

Second, a recent study of two fires in southern Oregon similarly reported that smaller headwater streams had characteristics similar to adjacent uplands (such as low composition of riparian deciduous hardwoods) that were associated with high riparian fire severity (Halofsky and Hibbs 2008). Research in dry inland forests of Oregon also showed that historical fire frequencies in riparian areas were comparable to those in adjacent uplands (the differences were not statistically significant), but high patchiness and mixed severity meant that many fires occurred only at a riparian plot or only in an upslope plot within a pair, but not at both (Olson and Agee 2005). In some areas, riparian fires may also be less frequent but more severe than those in uplands (Arno 1996, Everett et al. 2003). Aspect may be an important factor within landscape areas, as Everett et al. 2003 found that fire frequencies were more similar across site types on north-facing aspects (higher moisture and cooler temperatures) than on south-facing slopes. These studies demonstrate the wide variation in relationships between fire regimes across the riparian-upland interface.

Wildfire Effects on Riparian Areas

Kobziar and McBride (2006) studied the relationships between wildfire burn patterns, stream channel topography, and the short-term response of riparian vegetation to the Lookout Fire along two creeks in mixed-conifer forest in the northern Sierra Nevada (Plumas National Forest). The study streams were perennial (3 m wide) with 7.4- to 9.9-m-wide riparian corridors on their southern aspects. One stream burned at lower severity, with 53 percent of transects at low to moderate severity and 47 percent at moderate to high severity. In the other stream, 86 percent of transects burned at low to moderate severity and 14 percent burned at moderate to high severity. The entire riparian corridor burned only 14 to 26 percent of the time, and one-third of the study transects were not burned. The authors noted that wider floodplain terraces supported mountain alder, which has been shown to slow backing wildfires moving toward streams. That study found that postfire seedling recruitment and sprouting allowed riparian vegetation to be resilient and maintain stream quality even following high-severity fire. Wildfire effects on streams and aquatic systems are discussed more in chapter 6.1, "Watershed and Stream Ecosystems."

Influences on Riparian Functions

Stream Order

Distinctions between headwater streams and larger stream orders may be relevant for predicting fire effects and for disturbance-based management. The definition of headwater streams often differs, although first through third order may be a reasonable division for parts of the synthesis area. For example, streams of those orders often have very narrow riparian areas (1 to 3 m on a side in the Kings River Experimental Watersheds [KREW]) that have a unique plant community from the adjacent uplands (Dolanc and Hunsaker 2007). These distinctions may have an influence on management plans, because first- to third-order streams represent approximately 90 percent of all streams in the continental United States (Leopold et al. 1995). Agreement on delineation rules and verification of stream order and flow regime in the field is necessary to determine the extent of different stream types and to direct management to protect water quality and aquatic habitats (Hansen 2001). Streams at the fourth-order size up to large rivers usually support wider riparian areas and create a larger, moister microclimate; these downstream riparian areas likely impede some fires from burning all or some of their vegetation or crossing their stream channels.

Large Wood

Scientific literature has described the hydrological, ecological, and geomorphic effects of in-stream large wood and reported on the important role that large wood plays in linking upland, riparian, and aquatic portions of watershed ecosystems. Wohl and Jaeger (2009) provide a conceptual model of large wood loads and spatial distribution in streams of the Colorado Front Range that is summarized here as the findings may inform issues in the synthesis area. They note that in-stream large wood (LW) loads are generally highest in the headwater reaches, where trees are large and small channel size and stream power limit transport. Intermediate reaches often exhibit a dynamic equilibrium where LW pieces are moved out at approximately the same rate that they enter the reach. In headwaters and intermediate reaches, landscape disturbances like fire, windthrow, landslides, and debris flows are responsible for delivering large pulses of wood to streams. However, large, low-gradient streams and rivers are supply limited because of the larger proportion of open water compared to riparian contact area. Wohl and Jaeger (2009) surmise that stream reaches at lower elevations in the Colorado Front Range may have a deficit in LW resulting from historical reductions in supply and active removal of wood, whereas loads in higher elevation streams may be closer to a historical reference condition. If similar patterns occur for streams in the synthesis area, then their conceptual model might suggest that short-term reductions in LW from active management would pose little risk in small, low-order streams. However, Wohl and Jaeger (2009) also noted that local recruitment of wood is limited in reaches along large meadows and bedrock outcrops, which do occur in parts of the synthesis area.

Short-term reductions in large wood from active management would pose little risk in small, low-order streams.

Microclimate Effects

Riparian areas are supported by a moister, three-dimensional air and soil microclimate as compared with adjacent uplands. Rambo and North (2009) compared microclimate (air temperature and humidity) gradients in trees from near the forest floor up through the canopy for both upland and riparian-influenced forest trees (three trees for each landscape type). The study area was in the Teakettle Experimental Forest in old-growth mixed-conifer forest that received one of three treatments: none, understory thinning, or overstory thinning. Measurements were made at 5, 15, 25, 35, and 45 m above the forest floor. Riparian microclimate had significantly lower minimums and means, and greater daily ranges of temperatures and humidity. The largest temperature and humidity ranges were near the stream and forest floor. In summer, steep slopes cause drainages to be warmer than ridge tops from upslope winds in daytime, and cooler at night because of the downslope flow of cold air from surrounding higher terrain. Accumulation of cold air at night can result in a local temperature inversion in drainages. This phenomenon acts in conjunction with stream influence, which directly cools air temperature and indirectly supplies water for daytime evaporative cooling via plant transpiration. In another study assessing changes in microclimate conditions both vertically and horizontally from Teakettle Creek, Rambo and North (2008) found a very narrow area around the stream (< 5.0 m vertically and < 7.5 m horizontally) in which microclimate conditions differed from upland.

Recent Research

Prescribed Burning

Beche et al. (2005) published one of the few studies that focused on effects of prescribed fire in a Sierra Nevada riparian area. They examined prescribed fire effects in a mixed-conifer forest of the northern Sierra Nevada by comparing characteristics of the stream and its riparian zone in the burned watershed with those of five unburned watersheds (first- and second-order streams of low gradient). Effects were measured immediately and up to 1 year after the fire and compared with conditions 1 to 7 years prefire. They concluded that the prescribed fire either had no or short-lasting (≤1 year) impacts on the stream and its riparian zone. The prescribed fire in the riparian zone was patchy in terms of intensity, consumption, and severity; it consumed 79 percent of prefire fuels, 34 percent of total surface fuels, and 90 percent of total ground fuels. The prescribed fire significantly reduced percentage of cover of surface vegetation and plant taxa richness in comparison with unburned sites, but not plant diversity (Simpson's D). Community composition of understory riparian vegetation changed postfire, most likely as a result of the reduction in taxa richness and cover. Postfire riparian tree mortality (>11.5 in diameter at breast height) was only 4.4 percent. No postfire change occurred in large woody debris volume and recruitment or in the amount of fine sediment in pools. Some water chemistry parameters increased (SO^{4-}, total P, Ca^{2+}, and Mg^{2+}), and periphyton biomass decreased; however, these changes were short term (≤1 year).

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Macroinvertebrate community composition was affected 10 to 19 days postfire, but density, richness, and diversity were unaffected; furthermore, composition recovered within 1 year. These effects are discussed in more detail in chapter 6.1. Beche et al. (2005) explained that the limited observed impacts may be a result of the small portion (<20 percent) of the watershed area that burned, moderate topography, the low to moderate severity of the fire, and the below-average precipitation year that followed the fire.

In a study from the Lake Tahoe basin, prescribed burning in areas that included some ephemeral channels showed short-term (3-month) increases in calcium and pH but not a significant increase in the amount of soluble reactive phosphorus in stream waters (Stephens et al. 2004: 258).

Aspen Management

Aspen stands provide important ecological services, including habitat for diverse wildlife and distinctive understory plants (Kuhn et al. 2011). Recent studies have demonstrated the benefits of selective conifer removal in restoring aspen stands; studies have taken place on the Eagle Lake Ranger District (ELRD) and the Lassen National Forest (Jones et al. 2005, 2011). At the sites in Lassen, the removal treatments were conducted in concert with control of heavy grazing pressure, and harvest was selected over the use of fire to avoid damage to the aspen trees. Jones et al. (2005) reported that hand pile burning within the treated stands killed aspen roots and appeared to inhibit regeneration. Another recent study on the east side of the Sierra Nevada (Krasnow et al. 2012) found that conifer thinning was effective in stimulating aspen release, although one stand that lost old aspen trees may have been past a threshold for restoration. The study also found that prescribed burning could be an effective restoration tool for aspen, although it noted that wildland fire use that resulted in higher intensity might be more effective. A detailed and comprehensive review of aspen ecology management in the Sierra Nevada is found in Shepperd et al. (2006); with regard to water resources, it is important to note that they suggested a possible benefit to water yield of restoring aspen stands, although studies suggest that more research is needed on that topic.

Prescribed burning could be an effective restoration tool for aspen, although wildland fire use that resulted in higher intensity might be more effective.

Terrestrial Amphibians

Effects of fires of varying severities and timber harvest, and their interactions, on terrestrial amphibians have been proposed as an important topic for research (Hossack and Pilliod 2011). Appendix E of the Sierra Nevada Forest Management Plan amendment identified effects of fuels treatments as an important research topic, with a focus on site occupancy by the foothill yellow-legged frog. Other species that may be important to consider are slender salamanders in the genus *Batrachoseps*, within which several new species have been recently described in the Southern Sierra Nevada (Jockusch et al. 2012). A synthesis of wildfire effects on amphibians noted that four studies found negative effects on populations or individuals on lungless salamanders, especially in uncharacteristically severe burns (Hossack and Pilliod 2011). One of the four studies was from southern California, where large fires in 2003 reduced occupancy by the slender garden salamander (*B. major*) in burned chaparral; the authors suggested that the effect may have resulted from a reduction in moist litter rather than be a direct effect of the fire, because the amphibians tend to move underground during the summer wildfire season (Rochester et al. 2010). Within the synthesis area, Bagne and Purcell (2009) examined effects of spring prescribed burning in ponderosa pine forest on two species of terrestrial salamanders (*Ensatina eschscholtzi platensis* and *B. gregarius*). They found no strong adverse effects of the treatment, which resulted in patchy burn effects, although they cautioned that sample sizes in the study were small. A review of studies suggests that heterogeneity of burn patches could be important in maintaining resilient populations of these amphibians (Hossack and Pilliod 2011).

Box 6.2-1

Pending Research on Pile Burning

Recent research in the Lake Tahoe basin that examined effects of pile burning in riparian areas suggested that in most management settings, potential soil effects did not appear to be an overriding concern (see chapter 5.1, “Soils,” for details on soil heating, although water quality results of that study are still in review).

Researchers from Humboldt State University have conducted research on pile burning in aspen stands in the Tahoe basin; although published studies are pending, the authors have released a report (Dagley et al. 2012).

Research Gaps and Management Implications

Dwire et al. (2010) concluded that there is little information about specific and cumulative impacts of different fuels reduction treatments on riparian and aquatic ecosystems. Stone et al. (2010) similarly concluded that additional experimental studies of fuels treatment effects on aquatic and riparian ecosystems are needed before generalizations can be made across different forest types and local conditions. Study results are often quite variable and confounded by local effects of other past and current management activities (Wondzell 2001).

Luce et al. (2012: 52) enumerated a number of challenges for riparian management: "(1) the integration of existing riparian classifications with developments in landscape ecology that highlight the role of landscape position and location within watersheds; (2) prediction of changes to riparian vegetation in response to climate-related shifts in temperature and precipitation given local and regional characteristics, watershed condition, and disturbance regimes; and (3) maintenance of valued riparian functions." They placed significant emphasis on the need for basic inventory and monitoring data about aquatic ecosystems, including stream temperature data and detailed mapping of riparian and aquatic habitats.

The 1996 Sierra Nevada Ecosystem Project (SNEP) report included a chapter with recommendations for riparian management that included a prohibition on vegetation removal and ground disturbance within riparian zones, which was intended to benefit both riparian and aquatic habitats (Kondolf et al. 1996). That section emphasized the importance of riparian tree canopies within first- and second-order streams in blocking summer sun and moderating water temperatures, as well as stream loading of large wood and other organic matter from riparian trees. It also suggested a fixed buffer width of 150 ft based on typical tree heights in the Sierra Nevada, and it recommended adopting wider, variable buffer widths that could be increased to account for variation in the riparian community and hillslope and soil erodibility. They asserted that "even the natural role of disturbance…does not require, in most situations, active restoration of the landscape in order to secure the habitat conditions necessary for the area" (Kondolf et al. 1996: 1026). The SNEP recommendations are similar to those established by FEMAT (1993) in the Pacific Northwest around the same time. The Sierra Nevada Framework (USDA FS 2001, 2004) established similar buffers with restricted activities; however, this planning effort also called for research on management in riparian areas. However, recent science has shown that higher stem densities and fuel loads in riparian forests can serve as a wick for high-intensity fire to move within treated upland forests under some conditions, such as the Angora Fire in the Lake Tahoe basin (Murphy et al. 2007, Pettit and Naiman 2007, Van de Water and North 2011). More studies of variation across riparian areas are needed, but limited evidence does suggest that some of these forests are vulnerable to uncharacteristically high-severity fires under severe weather conditions; as a result, scientists have noted the importance of considering treatments in riparian areas as part of landscape-scale restoration strategies (Messier et al. 2012, Van de Water and North 2011).

Limited evidence suggests that some riparian forests are vulnerable to extreme fires and may benefit from treatment as part of landscape-scale restoration strategies.

Broad principles based upon recent science discussed in this synthesis suggest that more active management within riparian areas, including mechanical harvest, could promote resilience to uncharacteristically severe wildfire. The principles of restoring upland forests described in chapter 1.2, "Integrative Approaches: Promoting Socioecological Resilience," can extend to riparian areas. For example, it may be appropriate to design treatments to increase heterogeneity where it has been reduced. Customization to local conditions and consistency with principles designed to promote resilient soils (see chapter 5.1) would help to develop specific treatment approaches. Luce et al. (2012) suggested scenarios in which short-term risk may need to occur to promote a long-term benefit. For example, they considered that extending fuels reduction treatments into riparian areas may reduce effective shade for several years, while reducing the potential for severe wildfire and ultimately sustaining shade benefits over several decades.

Effects of fire suppression and lack of active treatment have contributed to high fuel loads, increased tree density, and shifted vegetation composition to less fire-resistant species in riparian areas as well as in uplands. Treatments should reduce the likelihood of high-severity wildfires where they are not characteristic of the landscape. Riparian areas support important resource values, they are well adapted to recovery from disturbance, and even uncharacteristically high-severity fires may not necessarily impair long-term recovery of key functions. Outcomes may depend on the extent and severity of fire in the surrounding landscape and the vulnerability of downstream aquatic resources (see chapter 6.1). Better information is needed to understand how uncharacteristically severe fire may alter trajectories in riparian areas over a range of time scales relevant to understanding particular ecological processes (such as aquatic life cycles, channel organization, recruitment of woody debris, etc.).

Rieman et al. (2003) stated that objectives for fuels reduction treatments should include the return to fuel loads that support ecosystem processes and natural disturbance regimes and incorporate short- and long-term targets for the vegetation condition of uplands and riparian areas. Fuel loads in many riparian forests are so high that mechanical treatments may be needed to reduce fuels to levels that facilitate safer reintroduction of fire. Studies in uplands show that mechanical fuels reduction treatments, if conducted properly (i.e., reducing surface and ladder fuels), can effectively reduce fire severity under most weather conditions (Safford et al. 2012). These treatments should work just as effectively in riparian areas, although higher productivity in riparian areas may necessitate more frequent maintenance.

Treating densely stocked riparian areas may not only offer benefits in terms of wildfire risk reduction and promotion of shade-intolerant riparian vegetation, but it may also yield benefits to aquatic systems. This idea has gained traction in the Pacific Northwest, where the use of riparian management areas has been widely adopted. For example, evidence suggests that light limitation of primary production often overrides nutrient limitation in small, forested streams (Wilzbach et al. 2005). Bisson et al. (2005) reported that following the 1980 eruption of Mount St. Helens, fish populations thrived in what would otherwise be considered undesirable stream temperatures owing to the presence of abundant food supplies. An early study by Murphy et al. (1981) had reported that small, steep streams traveling through clearcuts in the Oregon Cascade Range had greater aquatic productivity than streams in shaded forest reaches, although they cautioned that such treatments might have imposed effects further downstream. In a similar vein, Newton and Cole (2005) reported that stream buffers on the south side of streams in western Oregon appeared to support increased production of benthic insects while avoiding creation of temperature hot spots. Although these studies do not necessarily test proposed management strategies for the synthesis area, they point to the potential benefits of reducing riparian forest canopies in western forests, which should be considered as part of an adaptive management framework.

Riparian treatments would need to be evaluated and monitored to assess impacts and guide approaches in the future. There may be valuable opportunities to better link management and research. For example, Stone et al. (2010) interviewed Forest Service fire management officers in 11 Western States and found that 43 percent were conducting fuels reduction treatments in riparian areas (California had 7 of 12 districts with riparian treatments). Although 88 percent of the districts reported monitoring activities to evaluate the effectiveness or ecological effects of the fuels reduction treatments in riparian areas, most monitoring was qualitative or not collected with sufficient spatial and temporal replication for quantitative summaries.

The special nature of these systems warrants developing localized prescriptions based in part upon historical fire regimes. For instance, approaches should differentiate riparian areas that function similar to upland landscapes in terms of fire frequency and spread; as discussed earlier, stream order may be a useful distinguishing characteristic. Van de Water and North (2010) suggest that the following riparian types could probably be treated similarly to upland areas, including:

- Lower elevation riparian areas;
- Riparian areas adjacent to small, incised headwater streams that historically experienced fire at frequencies similar to those of upland areas; and
- Riparian areas surrounded by forests with a high proportion (about one-third of the basal area or greater) of fire-tolerant pines, especially those on the east side of the Sierra Nevada.

For other kinds of forested riparian areas, including those at higher elevations and those bordering wider streams, they recommended considering less intensive treatments, such as hand thinning and pile burning small trees (Van de Water and North 2010). Understanding the life history requirements of aquatic taxa will help to inform prescriptions in different contexts. For example, the Cascades frog (*Rana cascadae*) is an example of a species that appears to need open-canopy basking sites along the riparian corridor (Pope et al. 2014).

Adaptive management research is needed to develop guidelines for mechanical and prescribed fire treatments in riparian areas within the synthesis area.

An ongoing research experiment in eight Sierra Nevada watersheds in the mixed-conifer zone will provide new insight into restoration treatments in headwater riparian areas for both mechanical thinning and prescribed fire (see the box on KREW in chapter 6.1). However, the research gap is so large that more adaptive management research is needed to develop guidelines for mechanical and prescribed fire treatments in riparian areas within the synthesis area. Consequently, the approach of large experimental areas outlined in chapter 1.2 might incorporate adaptive management experiments within riparian areas to help fill this gap.

Literature Cited

Arno, M.K. 1996. Reestablishing fire-adapted communities to riparian forests in the ponderosa pine zone. In: Arno, S.F.; Hardy, C.C., eds. The use of fire in forest restoration. INT-GTR-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 42–43.

Bagne, K.E.; Purcell, K.L. 2009. Response of two terrestrial salamander species to spring burning in the Sierra Nevada, California. Res. Note RMRS-RN-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 10 p.

Beche, L.A.; Stephens, S.L.; Resh, V.H. 2005. Effects of prescribed fire on a Sierra Nevada (California, USA) stream and its riparian zone. Forest Ecology and Management. 218: 37–59.

Bisson, P.A.; Crisafulli, C.M.; Fransen, B.R.; Lucas, R.E.; Hawkins, C.P. 2005. Response of fish to the 1980 eruption of Mount St. Helens. In: Dale, V.H.; Swanson, F.J.; Crisafulli, C.M., eds. Ecological responses to the 1980 eruption of Mount St. Helens. New York: Springer: 164–181.

Dolanc, C.R.; Hunsaker C.T. 2007. Riparian and upland vegetation on the Kings River Experimental Watershed, Sierra Nevada, California. In: Powers, R.F., ed. Restoring fire-adapted ecosystems: proceedings of the 2005 national silviculture workshop. Gen. Tech. Rep. PSW-GTR-203. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 299.

Dagley, C.M.; Berrill, J.; Coppeto, S.; Jacobson, K. 2012. Effects of slash pile burning after restoring conifer-encroached aspen. South Lake Tahoe, CA: U.S. Department of Agriculture, Forest Service, Lake Tahoe Basin Management Unit. 10 p. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5406067.pdf. (13 December 2013).

Dwire, K.A.; Rhoades, C.C.; Young, M.K. 2010. Potential effects of fuel management activities on riparian areas. In: Elliot, W.J.; Miller, I.S.; Audin, L., eds. Cumulative watershed effects of fuel management in the western United States. Gen. Tech. Rep. RMRS-GTR-231. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 175–205.

Everett, R.; Schellhaas, R.; Ohlson, P.; Spurbeck, D.; Keenum, D. 2003. Continuity in fire disturbance between riparian and adjacent sideslope Douglas-fir forests. Forest Ecology and Management. 175: 31–47.

Forest Ecosystem Management Assessment Team [FEMAT]. 1993. Forest ecosystem management: an ecological, economic, and social assessment: report of the forest ecosystem management team, July 1993. USDA Forest Service; USDC National Marine Fisheries Service; USDI Bureau of Land Management, Fish and Wildlife Service, and National Park Service; Environmental Protection Agency. Portland, OR: U.S. Government Printing Office.

Fisk, H.; Megown, K.; Decker, L.M. 2004. Riparian area burn analysis: process and applications. RSAC-57-TIP1. Salt Lake City, UT: U.S. Department of Agriculture, Forest Service, Remote Sensing Application Center. 4 p.

Halofsky, J.E.; Hibbs, D.E. 2008. Determinants of riparian fire severity in two Oregon fires, USA. Canadian Journal of Forest Research. 38: 1959–1973.

Hansen, W.F. 2001. Identifying stream types and management implications. Forest Ecology and Management. 143(1-3): 39–46.

Hossack, B.R.; Pilliod, D.S. 2011. Amphibian responses to wildfire in the western United States: emerging patterns from short-term studies. Fire Ecology. 7(2): 129–144.

Jockusch, E.L.; Martinez-Solano, I.; Hansen, R.W.; Wake, D.B. 2012. Morphological and molecular diversification of slender salamanders (Caudata: Plethodontidae: Batrachoseps) in the southern Sierra Nevada of California with descriptions of two new species. Zootaxa. 3190: 1–30.

Jones, B.E.; Lile, D.F.; Tate, K.W. 2011. Cattle selection for aspen and meadow vegetation: implications for restoration. Rangeland Ecology and Management. 64(6): 625–632.

Jones, B.E.; Rickman, T.H.; Vazquez, A.; Sado, Y.; Tate, K.W. 2005. Removal of encroaching conifers to regenerate degraded aspen stands in the Sierra Nevada. Restoration Ecology. 13(2): 373–379.

Kobziar, L.N.; McBride, J.R. 2006. Wildfire burn patterns and riparian vegetation response along two northern Sierra Nevada streams. Forest Ecology and Management. 222: 254–265.

Kondolf, G.M.; Kattelman, R.; Embury, M.; Erman, D.C. 1996. Status of riparian habitat. In: SNEP Science Team and Special Consultants, eds. Sierra Nevada ecosystem project: final report to Congress. Vol. II: Assessments and scientific basis for management options. Report No. 37. Davis, CA: Centers for Water and Wildland Resources, University of California: 1009–1030.

Krasnow, K.D.; Halford, A.S.; Stephens, S.L. 2012. Aspen restoration in the eastern Sierra Nevada: effectiveness of prescribed fire and conifer removal. Fire Ecology. 8(3): 104–118.

Kuhn, T.J.; Safford, H.D.; Jones, B.E.; Tate, K.W. 2011. Aspen (*Populus tremuloides*) stands and their contribution to plant diversity in a semiarid coniferous landscape. Plant Ecology. 212(9): 1451–1463.

Leopold, L.B.; Wolman, M.G.; Miller, John P. 1995. Fluvial processes in geomorphology. Mineola, NY: Dover Publications. 544 p.

Luce, C.; Morgan, P.; Dwire, K.; Isaak, D.; Holden, Z.; Rieman, B. 2012. Climate change, forests, fire, water and fish: building resilient landscapes, streams, and managers. Gen. Tech. Rep. RMRS-GTR-290. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 207 p.

Messier, M.S.; Shatford, P.A.; Hibbs, D.E. 2012. Fire exclusion effects on riparian forest dynamics in southwestern Oregon. Forest Ecology and Management. 264: 60–71.

Murphy, K.; Rich, T.; Sexton, T. 2007. An assessment of fuel treatment effects on fire behavior, suppression effectiveness, and structure ignition on the Angora Fire. Tech. Pap. R5-TP-025. U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. 32 p.

Murphy, M.L.; Hawkins, C.P.; Anderson, N.H. 1981. Effects of canopy modification and accumulated sediment on stream communities. Transactions of the American Fisheries Society. 110(4): 469–478.

Newton, M.; Cole, E.C. 2005. Linkage between riparian buffer features and regeneration, benthic communities and water temperature in headwater streams, western Oregon. In: Harrington, C.; Schoenholtz, S., eds. Productivity of western forests: a forest products focus. Gen. Tech. Rep. PNW-GTR-642. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 81–101.

Office of the Federal Register. 2012. Subpart A: National Forest System Land Management Planning. In: USDA, ed. 36 CFR Part 219. U.S. Government Printing Office, Federal Register: 48–71.

Olson, D.L; Agee, J.K. 2005. Historical fires in Douglas-fir dominated riparian forests of the southern Cascades, Oregon. Fire Ecology. 1(1): 50–74.

Pettit, N.E.; Naiman, R.J. 2007. Fire in the riparian zone: characteristics and ecological consequnces. Ecosystems. 10: 673–687.

Pope, K.L.; Brown, C.; Hayes, M.J.; Green, G.; Macfarlane, D. 2014. Cascades frog conservation assessment. Gen. Tech. Rep. PSW-GTR-244. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 116 p.

Rambo, T.R.; North, M.P. 2008. Spatial and temporal variability of canopy microclimate in a Sierra Nevada riparian forest. Northwest Science. 82: 259–268.

Rambo, T.R.; North, M.P. 2009. Canopy microclimate response to pattern and density of thinning in a Sierra Nevada forest. Forest Ecology and Management. 257: 435–442.

Rieman, B.; Lee, D.; Burns, D.; Gresswell, R.; Young, M.; Stowell, R.; Rinne, J.; Howell, P. 2003. Status of native fishes in the western United States and issues for fire and fuels management. Forest Ecology and Management. 178(1–2): 197–211.

Rochester, C.J.; Brehme, C.S.; Clark, D.R.; Stokes, D.C.; Hathaway, S.A.; Fisher, R.N. 2010. Reptile and amphibian responses to large-scale wildfires in Southern California. Journal of Herpetology. 44(3): 333–351.

Safford, H.D.; Stevens, J.T.; Merriam, K.; Meyer, M.D.; Latimer, A.M. 2012. Fuel treatment effectiveness in California yellow pine and mixed conifer forests. Forest Ecology and Management. 274: 17–28.

Shepperd, W.D.; P. Rogers, P.; Burton, D.; Bartos, D.L. 2006. Ecology, biodiversity, management, and restoration of aspen in the Sierra Nevada. Gen. Tech. Rep. RMRS-GTR-178. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 122 p.

Skinner, C.N. 2003. A tree-ring based fire history of riparian reserves in the Klamath Mountains. In: Farber, P.M., ed. California riparian systems: processes and floodplains management, ecology, and restoration. Mill Valley, CA: Pickleweed Press: 116–119.

Skinner, C.N.; Taylor, A.H.; Agee, J.K. 2006. Klamath Mountains bioregion. In: Sugihara, N.S.; van Wagtendonk, J.W.; Fites-Kaufmann, J.; Shaffer, K.; Thode, A., eds. Fire in California's ecosystems. Berkeley, CA: University of California Press: 170–194.

Stephens, S.L.; Meixner, T.; Poth, M.; McGurk, B.; Payne, D. 2004. Prescribed fire, soils, and stream water chemistry in a watershed in the Lake Tahoe Basin, California. International Journal of Wildland Fire. 13: 27–35.

Stone, K.R.; Pilliod, D.S.; Dwire, K.A.; Rhoades, C.C.; Wollrab, S.P.; Young, M.K. 2010. Fuel reduction management practices in riparian areas of the western USA. Environmental Management. 46(1): 91–100.

Taylor, A.H.; Skinner, C.N. 2003. Spatial patterns and controls on historical fire regimes and forest structure in the Klamath Mountains. Ecological Applications. 13(3): 704–719.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2001. Sierra Nevada forest plan amendment: final environmental impact statement. Vallejo, CA: Pacific Southwest Region. http://www.sierraforestlegacy.org/Resources/Conservation/LawsPoliciesRegulation/KeyForestServicePolicy/SierraNevadaFramework/Framework-FSROD01.pdf. (13 December 2013).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2004. Sierra Nevada forest plan amendment: final supplemental environmental impact statement. Vallejo, CA: Pacific Southwest Region. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsBdev3_046095.pdf. (13 December 2013).

Van de Water, K.M.; North, M. 2010. Fire history of coniferous riparian forests in the Sierra Nevada. Forest Ecology and Management. 260(3): 384–395.

Van de Water, K.; North, M. 2011. Stand structure, fuel loads, and fire behavior in riparian and upland forests, Sierra Nevada Mountains, USA; a comparison of current and reconstructed conditions. Forest Ecology and Management. 262(2): 215–228.

Wilzbach, M.A.; Harvey, B.C.; White, J.L.; Nakamoto, R.J. 2005. Effects of riparian canopy opening and salmon carcass addition on the abundance and growth of resident salmonids. Canadian Journal of Fisheries and Aquatic Sciences. 62: 58–67.

Wohl, E.; Jaeger, K. 2009. A conceptual model for the longitudinal distribution of wood in mountain streams. Earth Surface Processes and Landforms. 34: 329–344.

Wondzell, S.M. 2001. The influence of forest health and protection treatments on erosion and stream sedimentation in forested watersheds of eastern Oregon and Washington. Northwest Science. 75: 128–140.