

Partial Harvest in Watercourse and Lake  
Protection Zones Using Low Ground  
Pressure Equipment to Support Fire  
Resilient, Ecologically Diverse Stands and  
Associated Ecosystem Services



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## Executive Summary

Unprecedented fire seasons in California have prompted land managers and resource professionals to take a closer look at management practices that may reduce the hazard for large, severe, destructive wildfire. Many scientific studies have identified that fire suppression activities have resulted in significant deviations from historical stand conditions in many of California's forests, particularly in the inland Sierra Nevada region. This trend carries over to riparian corridors, and in some cases is even more pronounced in riparian corridors due to policies limiting management in these areas aimed at protecting watershed processes and wildlife. In some cases, riparian corridors have been found to be overstocked and experiencing less frequent and more severe wildfires in places across the interior of the state. Resource professionals also see a "wicking" effect in riparian corridors, carrying fire through the landscape. With the impacts of climate change altering fire regimes and watershed function, the issue of management in riparian corridors to prevent catastrophic wildfire is particularly relevant.

The Board of Forestry and Fire Protection (Board) has prepared this guidance document for land managers and review team agencies to present the scientific basis for supporting the use of low ground pressure equipment in Watercourse and Lake Protection Zones (WLPZs) under appropriate site conditions and with implementation of Best Management Practices (BMPs) applied to support essential riparian functions. These BMPs can be considered for implementation by Registered Professional Foresters (RPFs), but are not required in the California Forest Practice Rules (FPRs) and may not be necessary, appropriate, or feasible in all cases. Use of equipment within WLPZs is already possible under the current FPRs as an in-lieu practice or with an approved Section V site-specific riparian prescription in Anadromous Salmonid Protection (ASP) rule areas; this document and its contents have no effect on the legal applicability of this practice. However, it should be noted that equipment use in WLPZs and the contents of this document only apply to the Plan process (as defined in 14 CCR 895.1), which is subject to CEQA review and approval by the Director of the California Department of Forestry and Fire Protection.

Two forms of forest management were considered in this paper – partial harvest and mastication. Timber harvesting and fuel reduction activities are fundamentally disturbances on the landscape and in sensitive areas such as riparian corridors, environmental considerations and impact assessments are especially important. Several environmental concerns arise with regard to soil and water quality, light and energy dynamics, and wildlife habitat and conservation. However, a literature review reveals that while harvesting or fuel reduction activities have the potential to negatively impact riparian and aquatic functions, these impacts become significantly less severe as BMPs are employed. As a result, in certain locations with high hazard for high severity fire which would severely impact watershed processes, the potential impacts from fuel reduction efforts may represent lower long-term impacts. Additionally, cultivating stands that are ecologically diverse and support riparian ecosystem services such as large

woody debris recruitment may require partial harvest or other forest management techniques.

BMPs identified in peer-reviewed literature:

1. Conduct operations only under dry or frozen soil conditions, or over snow
2. Use tracked equipment
3. Plan skid trails with attention to minimizing soil disturbance; clearly flag the skid trail; and include the Licensed Timber Operator (LTO) in the planning process when possible to ensure implementation of management objectives
4. Use skid trails with no sharp turns when possible
5. Place slash on the equipment pathway to reduce soil compaction
6. Minimize equipment passes on a single track
7. Implement equipment exclusion on areas that are steep or unstable and pre-flag these boundaries
8. Avoid disturbance to flood prone areas and poorly drained soils
9. Do not store or use chemicals in WLPZs; no refueling or servicing equipment in WLPZs
10. Avoid hydrologic connectivity between the area of disturbance and the watercourse;
11. Harvest on deep slash layers when possible
12. Do not place slash into watercourses or in areas where it is likely to enter the watercourse
13. Maintain adequate canopy cover, especially on the south side of watercourses
14. Maintain adequate sources of large woody debris, relevant to site-specific conditions and future needs
15. Employ directional felling away from the watercourse
16. Treat logging slash appropriately to reduce fire hazard and protect water and soil quality
17. Consider gap creation as a management technique

The Board supports the implementation of forest management in WLPZs on timberlands that exhibit high fuel loads that may contribute to severe wildfire or which may require management to support stand diversity and ecosystem services. Timber operations must be in compliance with the FPRs. The Board encourages all RPFs, land owners, and agency personnel to support timber operations in WLPZs when the body of evidence presented in this white paper and/or other appropriate sources are considered by the RPF and portions deemed appropriate by the RPF for the particular site under consideration are included in the project justification.

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## Introduction

The Board of Forestry and Fire Protection (Board) has received several comments expressing concerns that operational restrictions in WLPZs that limit management may be contributing to the size and severity of recent wildfires, exacerbated by California's history of fire suppression. When considering timber harvest in WLPZs, concerns arise with respect to aquatic and riparian habitat conditions, appropriate stand structure, and essential functions related to soil and water quality. However, recent conditions indicate that fire severity in riparian corridors located in the interior part of California may already be resulting in significant adverse effects on many of these critical functions. Moving forward, these management strategies require re-assessment and trade-offs must be considered. In some cases, the development of resilient forests may warrant the use of timber harvesting strategies that utilize low pressure ground equipment in WLPZs to prevent extreme fire conditions and subsequent soil, water quality, and species composition impacts.

Limited ground-based timber harvest activities in WLPZs are currently supported under the California Forest Practice Rules (FPRs) if explained and justified by a Registered Professional Forester (RPF) as an in-lieu practice or a Section V site-specific riparian prescription in ASP rule areas and approved by the Department of Forestry and Fire Protection. This white paper uses information from scientific studies to inform resource professionals where and when use of certain low ground pressure equipment in WLPZs may be appropriate to reduce wildfire severity while considering site-specific conditions and utilizing Best Management Practices (BMPs).

## Historical and Current Conditions of Riparian Forests

### Historical Fire Return Intervals

Many studies have illustrated that modern fire return intervals have deviated significantly from historical fire return intervals, with associated changes in intensity and severity. Van de Water and North (2010) present a model-based comparison of present and reconstructed fire histories and stand structures. Using three regions of the northern Sierra Nevada, dead trees with long fire histories were sampled in riparian and upland areas. Tree samples were analyzed to develop fire return intervals before and after 1850, as well as to determine the seasonality of burns. The study found that fire histories between upland and riparian areas were very similar, indicating that "riparian forests bordering many montane streams might be managed for fuel loads and fire return intervals similar to adjacent upland forests."

Several other studies indicate that historical fire regimes were often composed of frequent, low-intensity fires and highlight the importance of heterogeneity on the landscape. This diverse landscape results in a patchwork of fire severities that is better able to slow high-intensity fires while maintaining smaller areas of high-severity fire that can encourage stand diversity (Kilgore & Taylor, 1979).

## High Stand Density and Resulting Fire Regimes in Riparian Areas

Anecdotal evidence is noted in several studies, and the 2019 York and Roughton presentation suggests that stand densities in riparian corridors are higher than they have been historically and may be linked to increased fire behavior across the interior forests of California. Dr. York provided images in his presentation showing the difference between managed upland stands and riparian stands, with the riparian stands having significantly higher vegetation densities. Additionally, he noted that the Eldorado National Forest experienced the King Fire in 2014, which burned across riparian and upland areas near Blodgett Forest Research Station. A visual assessment of the land post-fire showed some live trees in upland regions and mostly dead trees in riparian corridors, indicating that the fire may have burned more severely in riparian areas.

Several empirical studies support this notion, indicating that stand densities are higher and stand composition dynamics are making these areas more fire-prone (Jurgensen et al., 1997; Van de Water & North, 2011). Van de Water and North (2011) suggest that California's history of fire suppression, limited management areas, and higher moisture content in riparian corridors have resulted in high stem densities and fuel loads. It has been proposed that the difference in spatial severity seen in the 2014 King Fire and in other recent fires may subsequently be the result of over-stocked riparian corridors.

In their 2011 study, Van de Water and North's model reconstructed historical stand conditions for riparian and upland forests. They then compared these reconstructed models to current stand conditions to approximate departure from historical stand conditions and fire regimes. They found that both riparian and upland forests have significantly greater basal area, stand density, snag volume, canopy bulk density, duff, and total fuel load when compared with the reconstructed stands. Also noted were significantly lower torching and crowning indices. A further comparison between current upland and riparian stands indicates that riparian forests have lower quadratic mean diameter, canopy bulk density, and proportion of fire-tolerant species; higher stem density and probability of torching; and greater predicted mortality than upland stands. Indeed, Van de Water and North state that "denser riparian stands composed of primarily fire-intolerant species with more vertical continuity of canopy fuels may result in higher riparian fire severity," and cite "observations of greater occurrence of crown fire near stream channels."

In contrast, reconstructed riparian and upland forests appeared to have no significant difference in fire intensity indices (Van de Water & North, 2010). Both upland and riparian stands have deviated from historical conditions, but riparian stands are more divergent from historical structures than upland stands, putting these areas at greater risk for high-severity fires and changes in ecosystem function. Finally, as linear landscape features, this increase in fire severity in riparian areas may also contribute to larger fires; over-stocked riparian areas have been hypothesized to act as "wicking"

agents along their length, sometimes carrying fire into unaffected upland areas (Murphy, Rich, & Sexton, 2007; Pettit & Naiman, 2007a; Van de Water & North, 2011).

### Impacts of High-Severity Fire on Water Quality and Site Productivity

In addition to anthropogenic impacts on stand density and composition in riparian areas, changes in climatic conditions are resulting in significant increases in tree mortality across the landscape. Longer and more intense droughts have become a common occurrence in California, resulting in increased drought-related mortality and susceptibility to pests and diseases. This increase in mortality contributes to fuel loads in riparian corridors and is likely to drive more frequent and more severe fires in the future (Pettit & Naiman, 2007; van Mantgem et al., 2013, 2009). The implications of these changes in fuel loading are wide-reaching, particularly in riparian areas where downstream effects can span miles of river.

Ice, Neary, and Adams (2004) summarize a variety of effects that may result from severe wildfires and highlight the importance of these impacts for riparian areas. As more severe fires burn closer to watercourses, impacts are more likely to affect watershed processes. Specifically, soil can be impacted by increased fire temperatures resulting in the exposure of mineral soil as the fire consumes organic layers. A layer of negatively charged, hydrophobic soil can also develop on the surface. Poor soil cover and a hydrophobic layer can result in dry ravel, reduced infiltration and percolation, increased surface flows and subsequent surface erosion, slope failures and debris torrents, stream in-fill, changes in nutrient cycling, changes in annual and peak flow, and related impacts to wildlife. For example, sediment yields and annual flow measurements have been shown to double or triple following wildfire, resulting in higher turbidity, increased channel scouring, changes in primary productivity in streams, and extreme water flows that may produce further bank failures or overloading of woody debris in streams (Dahm, Candelaria-Ley, Reale, Reale, & Van Horn, 2015; Ice et al., 2004). Soil health issues are compounded by reduced vegetation and canopy cover on riparian corridors post-fire, which can result in severe increases in stream temperature and reduced bank stability. Additionally, Dahm et al. (2015) note changes in stream pH, conductivity, and dissolved oxygen, which may strongly affect macroinvertebrate community structure and could produce hypoxic conditions.

As severe wildfire impacts on riparian and aquatic ecosystem processes and wildlife become more apparent, it is important to consider that fire severity and location are much stronger determinants for soil and watershed responses to fire than the presence of fire itself (Ice et al., 2004). Restoration of historical fire regimes and stand densities will be an important component of fire prevention in future years, and careful management of riparian areas to prevent adverse effects to water quality as well as riparian and aquatic wildlife will be essential.

### Restoring Pre-Colonization Stand Dynamics

In an environment that has evolved with fire serving as an integral part of the life cycle, it is not surprising that suppression practices have been associated with structural

and compositional changes in forests (Messier, Shatford, & Hibbs, 2012). Several studies have cited increased stand densities and increased fire severity in historically fire-prone areas, both of which have implications for stand complexity (Agee, 1998; Kilgore & Taylor, 1979; North, 2012).

Messier, Shatford, and Hibbs (2012) look specifically at fire exclusion effects on riparian forests, the impacts of reserve systems, and public policy related to forestry and prescribed burning in riparian corridors. They ask: do separate management strategies for riparian and upland forests with similar fire histories make sense; and how does fire exclusion in combination with these different management strategies affect riparian stand dynamics? Study results show that historical riparian forests were maintained by a mixed-severity fire regime which resulted in “complex, multi-aged stands with large, old fire-resistant trees” and a heterogenous nature that included gap creation and unburned areas for fire-sensitive species (Messier et al., 2012). Changes in this dynamic are resulting in higher retention rates in riparian corridors and subsequently higher stand density. This increased stand density favors more shade-tolerant species and prevents the gap creation that historically allowed for the establishment of new shade-intolerant conifer species, resulting in reduced heterogeneity in stand density, species composition, and age structure. Additionally, the preference for shade-tolerant species creates issues for wildlife, as large stream-side conifers are often important for woody debris recruitment and snag creation. With predicted lower future recruitment of these types of trees, these critical habitat features may decline. Messier, Shatford, and Hibbs (2012) conclude that current riparian management policies may be “detrimental to the long-term health of riparian forests in regions shaped by fire.”

Keane et al. (2002) reference similar conclusions; namely, that fire suppression and limited management are resulting in higher stand densities which may be having detrimental effects on riparian ecosystems. These effects can include: decreased biodiversity, increased crown and surface fuels, increased instances of fire-sensitive invasive species, increased pest infestations, changes in soil absorption, and changes in stand and landscape level composition and structure. Keane et al. (2002) cite many of the compositional and structural changes documented by Messier, Shatford, and Hibbs (2012), such as a shift to shade tolerant species, increased density, and changes in retention rates and successional patterns. However, Keane et al. (2002) also note the invasion and overgrowth of brush and shrubs into grasslands and shrublands because regular disturbance is no longer regulating the size and number of these fuels. This may also hold true in some forested lands with adequate light penetration to allow the growth of brush and shrubs, increasing surface and ladder fuels in these areas.

Keane et al. (2002) and Messier et al. (2012) both assert that neither thinning nor prescribed burning is independently sufficient to restore historical fire regimes. For the restoration of historical stand dynamics that are more conducive to lower severity fires, Keane et al. (2002) suggest the inclusion of thinning treatments as well as prescribed fire to restore ecosystem processes and prevent large, severe fires that kill more plants

and alter more ecosystem processes. Messier, Shatford, and Hibbs (2012) suggest that “large canopy gaps, un-treated ‘islands’, clumps and irregularly spaced trees” may be appropriate methods of thinning riparian areas to mimic historical disturbances, and that these treatments in addition to prescribed fire will “promote the recruitment of shade-intolerant, fire-resistant tree species, increase overall tree vigor, increase structural diversity, and create a more discontinuous forest canopy, restricting the spread of high-severity crown fires” (Messier et al., 2012).

#### Potentially Improved Habitat Conditions Resulting from Riparian Treatment

As detailed in previously referenced studies, wildfire has significant impacts on riparian areas and the wildlife that depend on them. This is particularly true in the case of high-severity fires, which are becoming more common in California due to climate change and an era of fire exclusion and limited management policies in riparian corridors (Dwire, Meyer, Riegel, & Burton, 2016). Changes to soil structure can result in declines in water quality and water infiltration, negatively impacting aquatic species and downstream habitat; changes in tree vigor, stand composition, and age structure due to overstocking can result in declines in woody debris recruitment and inadequate habitat for some riparian species; increased susceptibility to pest infestations due to limited management and environmental stress can increase surface fuels and result in increases in invasive plant species. The list of potential habitat degradations that can result from severe riparian fires is substantial. Indeed, these impacts have the potential to cascade through the ecosystem and downstream to many locations and species. Efforts to more closely mimic historical stand and fire dynamics in riparian corridors to shape a more frequent, less severe fire regime are essential for establishing fire resilience and restoring habitat value, which in turn support healthy water, soil, and wildlife. While operations with low pressure ground equipment can have significant impacts, several studies have stated that thinning efforts and prescribed burning may be a more controlled and less impactful method of management than the current fire regime, particularly when BMPs are employed (Keane et al., 2002; Messier et al., 2012; Scott, James, & Ralph, 2012).

## Ponderosa Fire (2012): A Case Study

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The 2012 Ponderosa Fire was a lightning caused fire that burned 27,676 acres and destroyed “52 dwellings, 81 outbuildings, 70 vehicles and 6 other personal holdings” (White & Grafft, 2012). This fire burned significant portions of Sierra Pacific Industries (SPI) landholdings in the area, and limitations on management in WLPZs have been pointed to as one of the conditions that allowed for the high spread and severity of this fire.

The LiNe Timber Harvesting Plan (THP) was prepared in 2014 by Sierra Pacific Industries (SPI) to develop a fuel break on land that is adjacent to the Ponderosa Fire. In this THP, SPI states: “Recent observations of wildland fire behavior are revealing that fire intensity can be very damaging to riparian areas because of the chimney effect of topography combined with elevated fuel loading. The proposed fuel break runs in a generally northwest/southeast direction crossing through valleys of major watercourses. Because of limitations imposed by 14 CCR 936 related to the degree of allowable alteration of vegetation within the WLPZ the effectiveness of this fuel break will not be optimized without the application of site-specific nonstandard operational provisions within WLPZs” (Mitzel, 2014).



*Figure 1: "Aerial photograph taken of the Ponderosa Fire, 2012, in Tehama County... (photo provided by Mark Lathrop, SPI)" (Liquori et al, 2012)*

Fuel loading was also estimated for each of the locations adjacent to watercourses being considered for fuel treatment as part of the fuel break development. Six of the eight watercourses considered had moderately high to very high fuel loads and the Plan preparers stated that "the elevated unbroken block of higher fuel quantities and connectivity lead to the expectation that fire momentum and severity will be greater as it burns up the draw than would be expected in upland areas," also citing the "chimney effect" on other watercourses. These assessments resulted in widening the proposed area on three of the eight watercourses to ensure functionality of the fuel break (Mitzel, 2014).

Figure 2 shows vegetation burn severity estimates for the 2012 Ponderosa Fire footprint based on the Composite Burn Index (CBI). The CBI is a moderate-resolution "landscape perspective of entire burned regions" based on visual assessments of large plots. These assessments track burn severity using the "magnitude of ecological change caused by fire" (Key & Benson, 2006). In many locations, high severity fire impacts correspond closely with riparian corridors, representing significant threats to water quality. These areas can be seen outlined in black. Additionally, Figure 1 shows an example of a severely burned riparian corridor "wicking" the fire through irrigated pasture in the Ponderosa Fire.

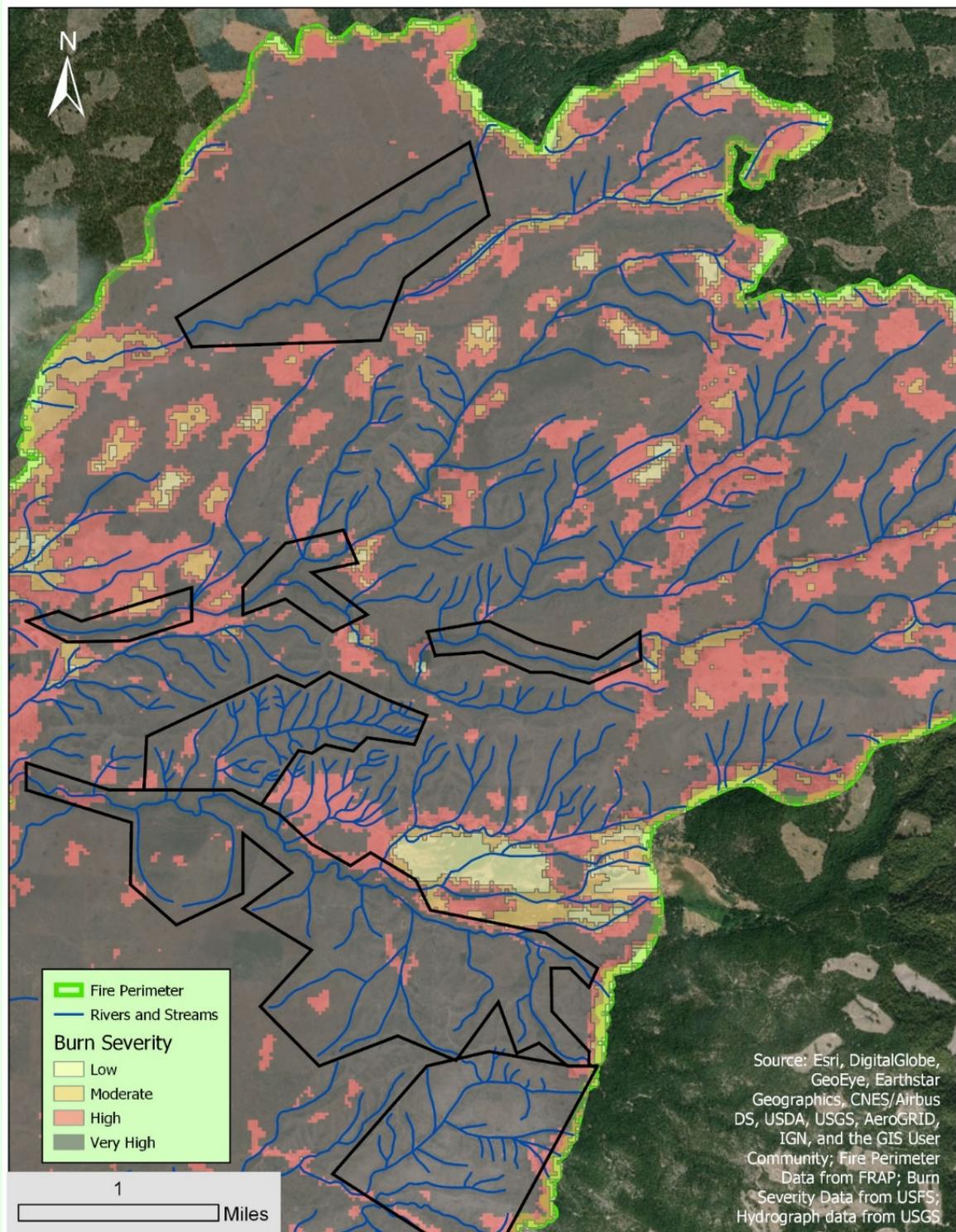


Figure 2: Section of the 2012 Ponderosa Fire in Shasta and Tehama Counties based on CBI data developed by USFS. Areas of interest are outlined in black.

While this increased severity is not present around every riparian corridor, its presence is significant given the history of low severity fires in riparian corridors. In particular, the small section outlined in the middle left of this map shows an area that is almost entirely enclosed by high and moderate severities, but has very high severity directly adjacent to the watercourse.

Additionally, the United States Forest Service (USFS) developed a Burned Area Reflectance Classification (BARC) map which is a “satellite-derived data layer of post-fire vegetation condition” that is measured by detecting differences in near and shortwave infrared radiation (USFS, n.d.). Figure 3 shows the increased severity near riparian areas in even greater detail.

- ❖ Note on Figure 3: The classes depicted on this map are based on a preliminary classification of the reflectance properties of the target area as recorded by a satellite sensor. The Burned Area Reflectance Classification (BARC) map is intended to support immediate post-fire assessment by Burned Area Emergency Response (BAER) teams. The BARC map can be used to guide the initial assessment of emergency watershed conditions. The BARC map may be modified to represent soil burn severity after proper field validation of soil characteristics. Using this map for other than its intended purpose may yield inaccurate or misleading results. The USDA Forest Service uses the most current and complete data available during immediate assessment of post-burn emergency conditions. Geospatial data accuracy may vary. The USDA Forest Service reserves the right to correct, update, or modify geospatial inputs to this map without notification.

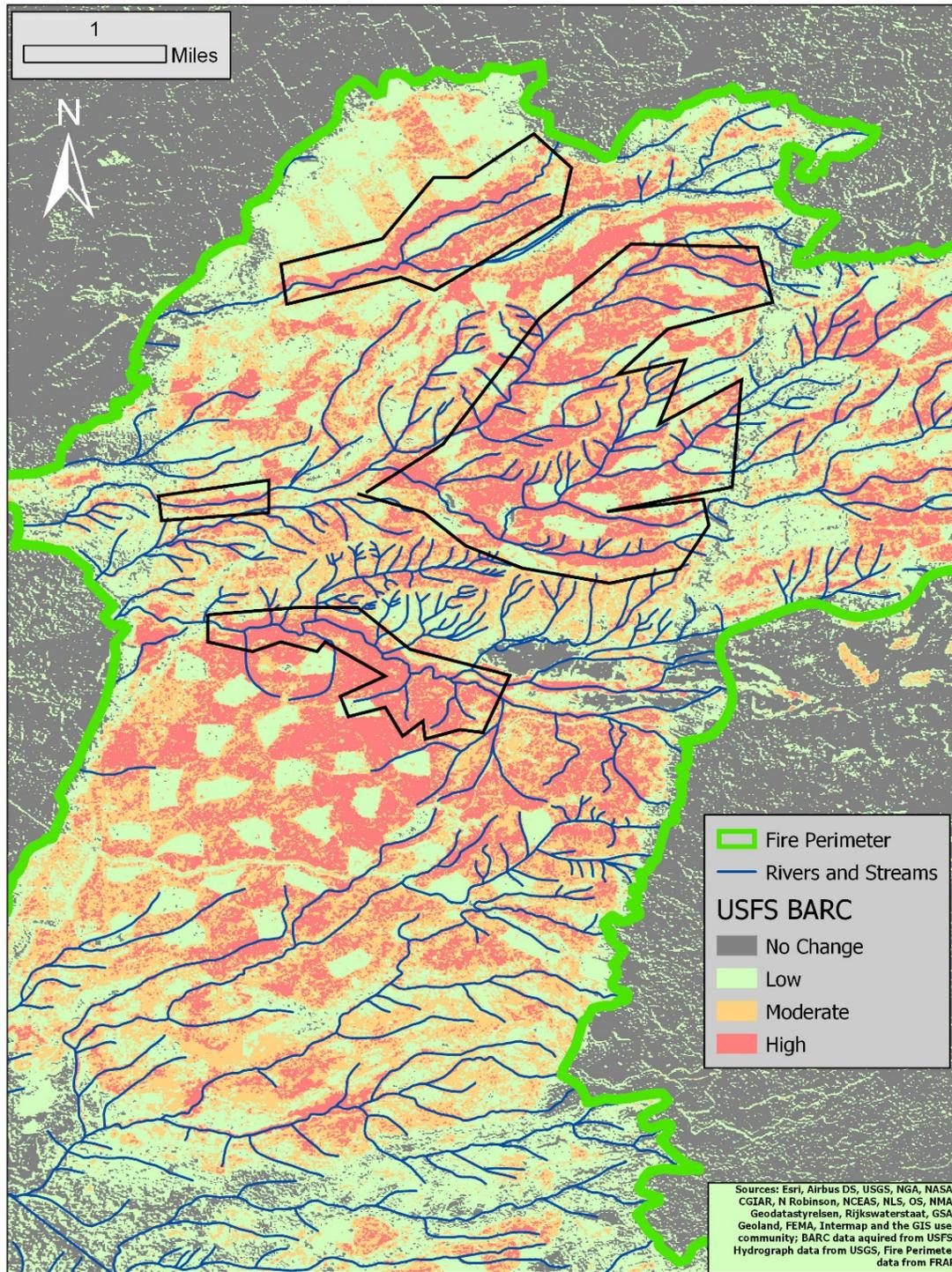


Figure 3: Section of the 2012 Ponderosa Fire, Shasta and Tehama counties, California based on BARC data developed by the USFS. Areas of interest that show high severity burning around watercourses are outlined in black.

In summary, the 2012 Ponderosa Fire and the concerns expressed by adjacent land managers in the following years indicate that management in WLPZs may be an important component of future maintenance of low-intensity fire regimes in riparian corridors in certain parts of the state.

## Environmental Concerns Related to Heavy Equipment Use in WLPZs

California is an extremely diverse state and contains several different forest types each of which have unique physical and biological properties that may affect their sensitivity and response to heavy equipment use. Additional differences in riparian and stream properties further contribute to these complexities and can result in different management considerations for specific regions or habitat types. For example, management considerations for coastal redwood and Sierra Nevada mixed-conifer forest will likely be different due to differences in soil type, climatic regime, vegetation type, terrain, etc.

Given California's historical management of riparian areas and the associated impacts of less advanced logging equipment, it is imperative that environmental considerations be included in any discussion of heavy equipment use in WLPZs. As discussed previously in the context of fire spread, watercourses serve as a key feature that links the landscape together. As such, any impacts to watercourses or surrounding riparian zones can result in impacts that reach far from the point of entry. This section is not intended to be an all-inclusive discussion of environmental concerns, as many concerns related to timber harvest are extremely site-specific. Rather, this section covers many of the most common concerns. Additionally, the body of evidence contained in this white paper reflects the most contemporary research, but has a wide geographic scope and may or may not apply to a given site.

### Soils

#### Soil Compaction, Runoff, and Changes to Site Productivity

Soil compaction and the associated implications for site productivity and water quality are some of the most commonly identified impacts of harvesting in riparian areas. As heavy equipment moves into these areas for harvesting, soils are put under pressure and the porous space between particles of soil becomes smaller. As these pores shrink in size and number, less water can percolate through them (Grigal, 2000). The results are 1) water is more prone to flow over the landscape, potentially carrying increased sediment loads into adjacent watercourses; 2) it is more difficult for new vegetation to establish roots, and more difficult for existing vegetation to adapt to changes in water availability resulting in depressed growth; and 3) residual vegetation becomes more stressed and may die, resulting in increased fuel loads (B. Poff, Koestner, Neary, & Henderson, 2011). Grigal (2000) echoes these findings and further asserts that the impacts of compaction can be compounded in areas with rutting by funneling runoff and sediment into waterways.

Froehlich and McNabb (1983) discuss these impacts at length, indicating that soils in the Pacific Northwest are particularly vulnerable to compaction due to low soil strength. Their paper describes the relationship between machine trips and increases in

bulk density, indicating that most compaction occurs during the first few passes (Figure 4).

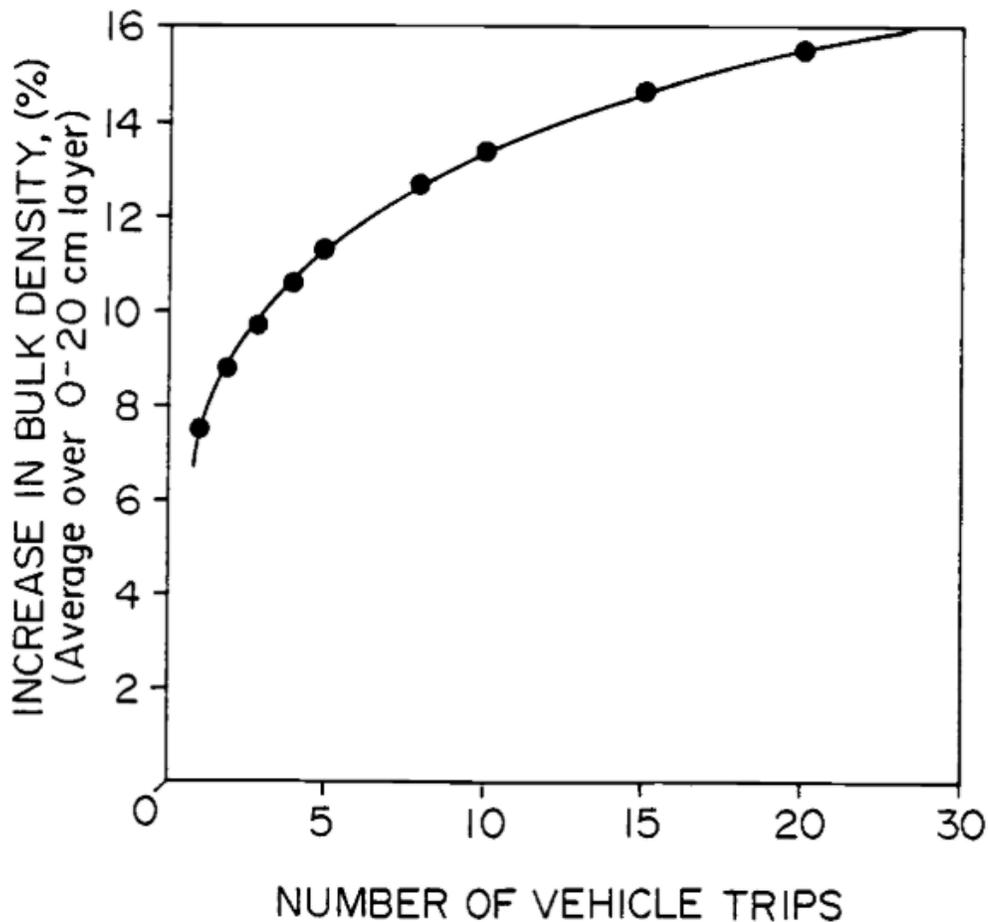


Figure 4: Increase in bulk density (a measure related to soil compaction) based on the number of equipment passes on a given area (Froehlich and McNabb, 1983)

They also document that increases in bulk density have negative consequences for soil processes such as soil aeration and water movement and can result in subsequent impacts on site productivity. Reductions in shoot growth have been observed following compaction, and Froehlich and McNabb (1983) found that “soil compaction affects volume growth more than it does height growth.” Further, this study indicates that these impacts are long-lasting and can be expected to persist for decades. The ecological implications for reduced site productivity are particularly important in riparian areas that depend on canopy cover for temperature regulation and wildlife habitat.

Powers et al. (2005) reported on the results from the first 10 years of the North American Long-Term Soil Productivity study and found similarly that soil bulk density increased under heavy equipment, but that the amount and type of impact varied

depending on a number of environmental characteristics present prior to compaction. For example, increases in bulk density were “greater for soils of low to moderate initial densities” and were minimal in soils that were dense before compaction treatments occurred. Powers et al. (2005) agrees that recovery of soil properties can be very slow, particularly in colder regions. It is also interesting to note that results show that understory competition can further reduce productivity on a site following compaction.

Finally, it is important to consider that based on the site’s soil type and hydrology, harvesting may not be appropriate or additional precautions may be needed to ensure the maintenance of soil function. For example, harvesting on wet areas including flood-prone areas and areas with poor drainage may increase the probability of compaction and rutting (Busse, Hubbert, & Moghaddas, 2014).

### Surface Erosion and Stream Sedimentation

Soil compaction can result in many site impacts, as discussed above. Specifically, as an impermeable surface is imposed on the landscape, water is concentrated and forced to flow over land, picking up sediment as it flows. Compaction accompanied by reductions in surface litter and vegetation cover can result in large amounts of surface erosion as natural barriers to erosive forces are removed from the system. These changes in the hydrology of a site can carry excess sediment to waterways, having subsequent negative effects on aquatic habitat. Additionally, while a more full discussion of soil types and their sensitivity to heavy equipment is not within the scope of this paper, decomposed granite soils are particularly vulnerable to impacts and warrant further consideration by the resource professional preparing the plan. Additional details on mitigation measures for consideration can be found in the 1991 paper titled “Recommended Mitigation Measures for Timber Operations in Decomposed Granite Soils” by the Department (CAL FIRE, 1991).

Studies by Rice, Rothacher, and Megahan (1972) and McCashion and Rice (1983) indicate that the most significant contributor to surface erosion in most logging systems is road construction, where adequate soil compaction is required. McCashion and Rice estimate in their 1983 study that approximately 40% of sediment from surface erosion originates from road systems. In fact, Rice, Rothacher, and Megahan (1972) assert that the action of logging itself contributes very little to these erosive processes. Instead, focus for preventative measures should be shifted to roads and yarding methods.

Lewis (1998) examined the impacts of logging on suspended sediment transport in the Caspar Creek Experimental Watersheds. Suspended sediment has been sampled from both the North and South Forks since 1962 with fluctuations in suspended sediment recorded following logging operations in the early 1970’s and in the 1990’s under the modern FPRs. The results indicated that suspended sediment increased by 212% over a 6-year period following tractor logging operations in the 1970’s without modern FPRs and 89% following logging in the 1990’s with modern

practices and primarily cable yarding. Lewis (1998) asserts that the difference in impact is the result of “differences in road alignment, yarding methods, and stream protection zones.” Improved management had a significant effect on reducing erosion inputs to waterways from timber harvesting. In addition to these reductions in potential impacts, a study by Nitschke (2005) indicates that sedimentation is increased more by severe wildfire than by harvesting because wildfire tends to disturb larger areas, reduces surface cover, and may create a layer of hydrophobic soil, further reducing permeability in the affected areas. The only exception that was found echoes the idea that roads are usually the greatest source of total and continuous sediment and enforces the concept that careful management and maintenance of roads and skid trails is one of the most important components for reducing surface erosion.

### Nutrient Input and Cycling

Nutrient leaching that can be exacerbated by increases in surface erosion is a concern following timber harvesting because there are fewer plants taking up the available nutrients. The organic and inorganic nutrients that remain in the soils can be vulnerable to erosive forces, resulting in less productive soils, increased susceptibility to insect pests and fungal infections, and changes in water quality in adjacent water bodies (Jurgensen et al., 1997). The literature indicates some disagreement about the severity of impacts to watercourses and soil productivity. Nutrient leaching and other soil and water chemistry impacts are site-specific and depend on a wide variety of factors including soil type and structure, tree type(s), existing soil chemistries, and climate (Dahlgren, 1998; Feller, Lehmann, & Olanski, 2000; Jurgensen et al., 1997; Nitschke, 2005).

Changes to levels of organic forms of nitrogen, phosphorus, and carbon are of particular concern with relation to nutrient leaching because studies indicate that they may take longer to recover (>50 years), can be more severe, and can have great impacts on key watershed processes (Jurgensen et al., 1997; Nitschke, 2005). Jurgensen et al. (1997) and Dahlgren (1998) assert that organic matter losses are often associated with soil mixing during harvest and increased microbial activity post-harvest. This organic layer of soil is important for insulating lower layers from changes in moisture and temperature as well as preventing erosion. Increased erosion following decomposition can carry organic carbon, nitrogen, and phosphorus into watercourses, resulting in increased aquatic primary productivity. Nitschke (2005) states that fluctuations in dissolved organic carbon in waterways can increase post-harvest and may have some of the most detrimental effects on streams. In contrast, some of the effects of additional organic inputs to streams do not seem to carry too far downstream – Dahlgren’s 1998 study at North Fork Caspar Creek showed that “nitrate concentrations were near those of the nonperturbed reference watersheds” by the time the stream left the experimental watershed (approximately 1,000 m in length). However, other papers indicate that the losses of organic matter from the harvesting site can have long-lasting impacts on site productivity (Nitschke, 2005). Nitrogen serves as the limiting nutrient in many Pacific Northwest forests and is of particular concern (Dahlgren, 1998).

Inorganic nutrients are also subject to leaching and may impact site productivity and water quality. Nitschke's study (2005), based largely in the Pacific Northwest and Western Canada, shows that harvesting can impact water quality by decreasing total sulfate and increasing total phosphorus, calcium, magnesium, sodium, nitrate, and ammonia. However, Feller, Lehmann and Olanski (2000) found that in southwestern British Columbia, fluctuations from mineral soils were relatively low, with the only significant changes occurring in potassium nitrate, indicating instead that fluctuations in organic nutrients were more significant.

Site differences further complicate management for this attribute, as many factors can impact how much nutrient leaching occurs. For example, Dahlgren (1998) found minimal impacts in the Caspar Creek Experimental Watershed and attributed this to the ability of California coast redwoods to sprout from stumps, thus increasing the nutrient sink on-site and preventing leaching. Additionally, in regions of Washington, Oregon, Idaho, Montana, and Wyoming, Jurgensen et al. (1997) suggest leaving some woody debris on-site to help maintain biodiversity and nutrient content in soils by mitigating erosion. However, this study also recognizes the difficulty in determining how much woody debris is enough, and concludes that this management tool is extremely site-specific and depends on a number of factors, including fire hazard.

### Mass Wasting and Stream Sedimentation

Mass wasting events – the process by which large amounts of sediment are moved and may enter waterways rapidly, such as landslides, are another significant source of stream sedimentation that may be of concern when conducting timber operations close to watercourses. Studies have shown that timber operations and associated road construction can result in reductions in site stability as vegetation is removed or killed and the remaining roots begin to decay (Dhakal & Sidle, 2003; Rice et al., 1972; Swanson et al., 1987). Additionally, steeper slopes and higher harvest percentages can increase the number of mass wasting events and the total volume of soil movement.

The 2003 study by Dhakal and Sidle in British Columbia examined frequency and volume of landslides associated with clearcutting, partial cutting (90%), and partial cutting (75%) over 50% or 100% of an area. Their results indicated that 75% partial cutting “did not produce significant landslide volumes compared to other harvesting practices.” Dhakal and Sidle also studied the effects of different harvesting intervals in British Columbia and found that increasing the interval between clear cut and partial harvesting (e.g. 10, 20, 30, 40 years between harvests) resulted in fewer mass movement events for clearcutting and partial cutting. Finally, they investigated the impacts of “leave areas” on slopes  $>40^\circ$  and the impacts of understory vegetation and found that the use of leave areas resulted in 1.8-2.9 fold decreases in landslide events and that the maintenance of appropriate understory vegetation resulted in 3.8-4.8 fold reductions in landslide events (Dhakal & Sidle, 2003).

However, several studies also indicate that the main cause of most post-harvest mass wasting events is poor road construction or road construction on inherently unstable areas (Nitschke, 2005; Rice et al., 1972; Swanson et al., 1987). Indeed, available literature indicates that the dominant source for most sediment production in timber harvesting systems is roads. For the purposes of this paper, road construction is not a practice that is permitted in WLPZs except at watercourse crossings, so soil specific impacts can best be addressed through skid trail designs and tree selection techniques. Additionally, heavy equipment use should only be proposed on limited sites after full consideration of slopes, soil type, and soil moisture.

## Flow and Energy Characteristics

### Summer Stream Flows

Studies by Keppeler (1998), Keppeler and Ziemer (1990), and Lewis et al. (2001) look at the impacts of logging activity on stream flows in the Caspar Creek Experimental Watershed. Keppeler (1998) indicates that evapotranspiration in the Caspar Creek watershed is estimated to consume half of the annual rainfall. This portion of the area's water budget is then returned to the atmosphere and does not reach the stream. Timber harvesting, fire, and other disturbances can alter this trend by reducing the amount of water taken up by plants, and allowing that water to penetrate the soil to be released in the dry summer months. Their study saw increases in total annual flow and summer flow, explained by the additional retention of 100 mm (of 660 mm estimated to be lost to evapotranspiration) following 50% harvest. However, this number is not closer to 50% additional retention in part because soil moisture conditions can impact how much additional water can be absorbed post-harvest. These increases in summer stream flow may result in positive outcomes for aquatic species by maintaining connectivity in streams and helping to moderate water temperatures (Keppeler, 1998).

However, Keppeler and Ziemer (1990) found increases in annual flow that they largely attributed to increases in flow during the wet season in Caspar Creek. In British Columbia, Nitschke (2005) also reports decreased summer flows resulting from low infiltration rates and high runoff in the wet months, indicating that the soil type and local hydrology are important for determining the possible impacts of timber harvesting on stream flows. Keppeler and Ziemer (1990) also express concerns about the tradeoffs between increases in annual flow and the potential for increased sediment inputs and impacts to water quality. For example, Lewis et al. (2001) sites an annual sediment load increase of 123-269% in tributaries for total or partial clear cut systems in the Caspar Creek Experimental Watershed.

### Light Availability and Energy Dynamics

Reductions in canopy cover can have serious impacts on the energy dynamics of stream communities. Canopy cover serves as one of the limiting factors for primary productivity in streams, often resulting in some dependence on terrestrial sources of carbon (Kaylor, Warren, & Kiffney, 2017). As more light reaches streams, aquatic primary productivity can spike, resulting in associated trophic cascades with unknown

consequences. The effects are extremely site dependent and can fluctuate based on available nitrogen and mineral nutrients, but positive implications for macroinvertebrates and salmonids due to increased food production are possible and have been found in a number of streams in coastal Northern California (Warren et al., 2016; Wilzbach, Harvey, White, & Nakamoto, 2005).

Kaylor, Warren, and Kiffney (2017) and Warren et al. (2016) both indicate that light and energy dynamics in forested riparian areas are more complicated when considering long-term stand dynamics. These studies suggest that many Pacific Northwest riparian forests may be in stem exclusion phases where canopy closure is complete and new seedling growth is stunted. They also show that previously logged areas when compared with old-growth stands differ significantly in light penetration – old-growth stands have significantly higher penetration that results from more heterogeneity and gap creation. Warren et al. (2016) contains several conceptual diagrams showing stand succession, all of which end in a mature gap dynamic that allows for heterogeneity in canopy cover, species composition, age structure, and light availability (discussed further under “Appropriate Post-Treatment Stand Dynamics”). Regardless of harvest intervention, Warren et al. (2016) anticipate significant changes in light availability and canopy closure in the next 50-100 years.

### Stream Temperatures

Water temperature is an important physical characteristic for aquatic biota and changes to temperature regimes can have significant impacts on these systems (Davies & Nelson, 1994; Kaylor et al., 2017; Moore, Spittlehouse, & Story, 2005; Nitschke, 2005; B. Poff et al., 2011). Moore, Spittlehouse, and Story (2005) discuss the impacts of timber harvesting on riparian microclimates and, by extension, impacts on aquatic thermal regimes. Riparian microclimates are typically more humid and have narrower temperature ranges as a result. Removal of timber in these areas can result in higher wind speeds which can increase evaporation and reduce humidity, contributing to greater air temperature ranges. This outcome, coupled with decreased shading can result in significant increases in stream temperature. In fact, Moore, Spittlehouse, and Story (2005) cite a study by Tyler Scott Ledwith (1996 Masters Thesis at Humboldt State University) which showed decreases in air temperatures above streams of 1.6 °C per 10 m of buffer width up to 30m.

A 30m buffer width is generally accepted as the threshold for protecting riparian areas from serious microclimatic and thermal impacts (Davies & Nelson, 1994; Moore et al., 2005). However, Nitschke (2005) suggests that retention harvesting may allow for more adequate shading and maintenance of riparian microclimates and would more closely mimic a lower intensity fire regime. Additionally, the impacts on thermal regimes seem to be short-lived in many cases (recovery within five to ten years) and are “unlikely to produce substantial changes in the temperatures of larger streams into which they flow” (Moore et al., 2005).

## Post-Harvest Forest Conditions

### Exotic and Invasive Species

Concerns related to invasive species are two-fold for timber harvesting activities. First, with heavy equipment entering work sites and materials being brought in from external sites, there are many opportunities to spread invasive plants from other locations (Ledoux & Martin, 2013). Second, harvesting often disturbs soils and creates canopy openings that can result in more favorable conditions for invasive species to establish themselves. The introduction of invasive species into new areas and the spread of invasive species in infested areas may by extension have serious implications for local wildlife, vegetation composition, and overall forest health. However, Ledoux and Martin (2013) indicate that by employing a series of BMPs, this issue can be managed if planning of operations includes considerations to prevent the spread of invasive plants.

### Residual Stand Damage

Anytime heavy equipment is used in a forested landscape concerns regarding residual stand damage should be considered. As large equipment moves through stands that are seldom evenly spaced and often on uneven terrain, there is high probability that the equipment or the logs in tow may strike a tree that hasn't been harvested and negatively impact stand health as well as the economic value of the remaining trees (Akay, Yilmaz, & Tonguc, 2006). Damage can occur anywhere on the tree (crown damage, trunk scarring, or root damage) based on harvesting and yarding techniques, and can therefore carry different implications for overall stand health and individual tree impacts.

Several studies have compared relative impacts on residual stands that result from different harvesting and yarding techniques, and have found that harvesters and forwarders can be viable tools that help minimize stand damage under certain conditions (Akay et al., 2006; Han & Kellogg, 2000; Limbeck-lilienau, 2003). However, not all impacts can be avoided using these logging systems, and attention should be paid to the use of BMPs to minimize impacts.

### Adequate Slash Disposal and Fuel Loading

Treating slash is important because it can enter watercourses and presents a serious fire hazard. Fahnestock (1960) conducted a study on the flammability, rate of spread, and fire severity associated with various slash characteristics. For adequate slash disposal, consideration of site-specific conditions such as relative humidity, species composition, amount of sunlight reaching the ground, fire seasons, and age of slash is imperative. These characteristics may inform when slash is treated, how much is treated, and how it is treated. Planning for slash disposal early in the harvesting process will support the overall management goal of reducing fire hazard in riparian areas.

## Appropriate Post-Treatment Stand Dynamics

As an ecosystem altering process, timber harvesting can inspire significant concerns with stand structure, species composition, and the general successional characteristics of riparian forests. Particularly with selection harvesting methods, potential long-term implications for fundamental ecosystem functions can result based on the species that colonize the empty spaces, at what rate, and how those outcomes shape canopy diversity. As previously discussed, levels of heterogeneity in stand age and species dynamics were historically high (Messier et al., 2012). Riparian areas were dominated by multi-age stands with some even-aged patches, some unburned patches, and a mix of hardwood and softwood species that were periodically thinned by fire or other disturbances. The frequent disturbances in this regime allowed for shade-intolerant species like large, commercial conifers to recruit in canopy gaps and these species offer a variety of ecological benefits including terrestrial wildlife habitat, large woody debris, and stream shading. Limited management in riparian areas has resulted in more shade-tolerant hardwood species recruitment due to decreases in the frequency of disturbance necessary to create sufficient gaps for the historically dominant softwoods and may have long-term implications for wildlife (Messier et al., 2012).

As a result, Messier et al. (2012) suggest that timber harvest via gap creation may mimic historical disturbances enough to encourage more historical forest succession and associated levels of diversity. However, conducting these operations appropriately to maintain the right levels of diversity and minimize impacts will be crucial to adequate management. Several studies indicate significant changes in diversity for species and age classes in stands logged with selection harvesting (Ferry Slik, Verburg, & Kebler, 2002; Hall, Harris, Medjibe, & Ashton, 2003; Saiful & Latiff, 2014). There are relatively mixed reviews of the specific impacts on stand diversity measures, but these three studies agree that the most significant impacts occur immediately after harvesting and that recovery can take 10-20 years, with one study citing reduced basal area 18 years after logging that was attributed to “the physiological stress associated with sudden crown exposure, and damage to the residual stand” (Hall et al., 2003). Also noted for extremely selective practices were increases in shade tolerant species from one quarter of the original basal area to almost half (Hall et al., 2003) and increases in the total percent cover of rare plants, but decreases in the total number of rare species (Saiful & Latiff, 2014).

It is without doubt that harvesting has the potential to have significant impacts on stand diversity, but a comparison between heavily burnt stands and harvested stands indicates that management decisions in landscapes with historical fire suppression may not be easy (Ferry Slik et al., 2002). Ferry Slik et al. (2002) investigated a variety of diversity measures following harvesting and burning and found that the Fisher's- $\alpha$  Index (a species evenness measurement) was within the range for primary forest one year after harvest and increased to pre-harvest levels about 20 years after harvesting, but not after burning. In fact, for burning the Fisher's- $\alpha$  Index regression mimics a classic decay curve, leveling off after 20 years at an approximate value of 25, with the primary

forest value estimated at approximately 80. Ferry Slik et al. (2002) do, however, caveat these findings by indicating that the studied forests were heavily burned, and that stands with stocking levels and fuel loads that can achieve a lower burn intensity may change the outcome of species diversity indices. Hall et al. (2003) conclude by proposing that carefully executed increased canopy disturbance may be the best solution for managing forests for economic and ecological resiliency by creating opportunities for shade-intolerant and high quality timber species to recruit. Mimicking historical disturbances through regular harvesting and maintenance of ground fuels may be an avenue for multi-purpose management of California's forests and may help restore certain riparian sites that are determined to require management.

### Botanical Resources

Timber harvesting is fundamentally a disturbance on the landscape, and sensitive plant species may be impacted by landscape alterations such as those detailed in previous sections (Golec, LaBanca, & Leppig, 2007; Halpern & Spies, 1995). Indeed, these changes in composition may persist for years following harvest (Gross, 2009). However, our understanding of sensitive and rare plants and their responses to specific timber harvesting practices is still very limited (Golec et al., 2007; Halpern & Spies, 1995).

Halpern and Spies (1995) discuss plant diversity in commercially managed landscapes in the Pacific Northwest and the relationships between plant diversity and forest succession following harvest. They generally noted a decrease in diversity following harvest that began to recover quickly to exceed old-growth levels, but the recovery rate of specific plots depended largely on the intensity and frequency of disturbance. In more intensely harvested systems, resource availability and habitat fragmentation become serious concerns. For species that need shade or very specific microclimatic conditions, for example, harvesting of large numbers of trees may not leave adequate habitat and fragmentation may not enable these species to colonize adjacent areas as readily. Harvesting has the potential to eliminate species if these kinds of alterations are not considered during planning. However, their study also indicates that the maintenance of heterogeneity on the landscape through less intensive harvesting techniques may help to ameliorate some of these impacts by providing diverse habitat for a variety of species. For the limited scope of this paper and the harvesting methods being considered, significant long-term impacts to botanical resources are expected to be minimal.

This assertion is supported by the Heavenly Creek Demonstration Project in the Lake Tahoe Basin Management Unit of the United States Forest Service (Gross, 2009). For this project, low-pressure ground equipment entered Stream Environment Zones (SEZs) to perform limited removal of fuels to reduce fire hazard. A monitoring effort accompanied this project which measured plant abundance and diversity before treatment and, most recently, nine years post-treatment. Results show that for native herbaceous cover (including graminoids and forbs), native shrubs, and non-native

invasive species, total cover did not differ significantly from pre-treatment values. Additionally, no significant changes in a variety of diversity indicators were detected from this study. However, decreases were measured in each of these categories in the first one to three years, followed by a recovery period.

It is also important to consider that while overall trends may not be concerning, changes at smaller scales were significant in some cases and may result in site-specific impacts. For example, while invasive plants did not increase as a group, two species increased significantly in some plots and may be of concern. Halpern and Spies (1995) echo this trend, indicating that site-specific impacts may differ significantly from overarching trends with regard to changes in abundance, diversity, and recovery time. Generally, the Heavenly Creek Demonstration Project is considered a success with minimal impacts on botanical resources, but prevention measures for invasive species and harvest plans that consider habitat retention will be important for maintaining diversity of sensitive and rare plants in forested landscapes.

### Riparian and Aquatic Wildlife

To manage multi-use areas, it is important that habitat quality for riparian and aquatic wildlife be maintained. The culmination of previously discussed impacts can have positive or detrimental effects on wildlife or disrupt food webs. Fuchs, Hinch, and Mellina (2003) and Kreutzweiser, Capell, and Good (2005) studied the impacts of selection harvesting on aquatic macroinvertebrate communities in British Columbia and Ontario, respectively, and generally found minimal impacts on species diversity, with some slight changes in single species abundance. Increased primary productivity due to increased fine organic sediment (Kreutzweiser et al., 2005) and increased light availability (Fuchs et al., 2003) may be resulting in increased macroinvertebrate biomass. However, no significant differences in the relative abundance of specific feeding guilds were seen. These findings are further echoed by Bottorff and Knight (1996) in the Caspar Creek Experimental Watershed. Specifically, they found increases in abundance and diversity of macroinvertebrate species related to increases in algae from increased solar radiation, nutrient input, and temperatures post-harvest. Significant declines are described from other studies by Kreutzweiser, Capell, and Good (2005), but these previous studies were largely in areas of clear cut or intensive logging.

Salmonid protection concerns under current FPRs are discussed in the Technical Advisory Committee (TAC) Primers prepared under the Board of Forestry and Fire Protection for the development of the ASP Rules in 2007. These primers detail the potential impacts of timber harvest on biotic, nutrient, wood, heat, water and sediment exchanges in riparian areas. Increases in sediment delivery after timber harvest have the potential to impact key stages of salmonid spawning and development, depending on the scale and severity of sedimentation. For example, sediment can reduce suitable habitat for redd excavation, fill pools that are used by adults and juveniles for rest and hiding, suffocate eggs, and result in developmental delays in juveniles. However, the

TAC also found erosion rate reductions of nine-tenths under modern FPRs when compared with pre-FPR (1975) harvesting methods.

The TAC Primers also discuss several abiotic factors that may influence salmonid survival, including light, nutrients, heat, and flow. These characteristics are heavily site-specific and vary in California largely in a predictable west to east gradient depending on differences in climate, geology, and hydrology. As discussed earlier, the potential for these abiotic factors to impact primary productivity and subsequently the macroinvertebrates that salmonids depend on is great and depends on which abiotic component is the limiting resource at a given site (e.g., light, nitrogen, phosphorus, dissolved organic matter, water). Changes in stream temperature are equally important for salmonid survival because they can directly impact rates of metabolic efficiency, feeding rates, and as a result, growth rates (Figures 5 and 6). Issues of temperature moderation are particularly significant in the Coastal Anadromy Zone where shading is key for temperature regulation and salmonid species. Several watersheds in this zone are federally listed on the 303(d) list for temperature and timber operations near a listed watercourse may not be appropriate to achieve ecological objectives (Board, 2015).

### Coho Salmon

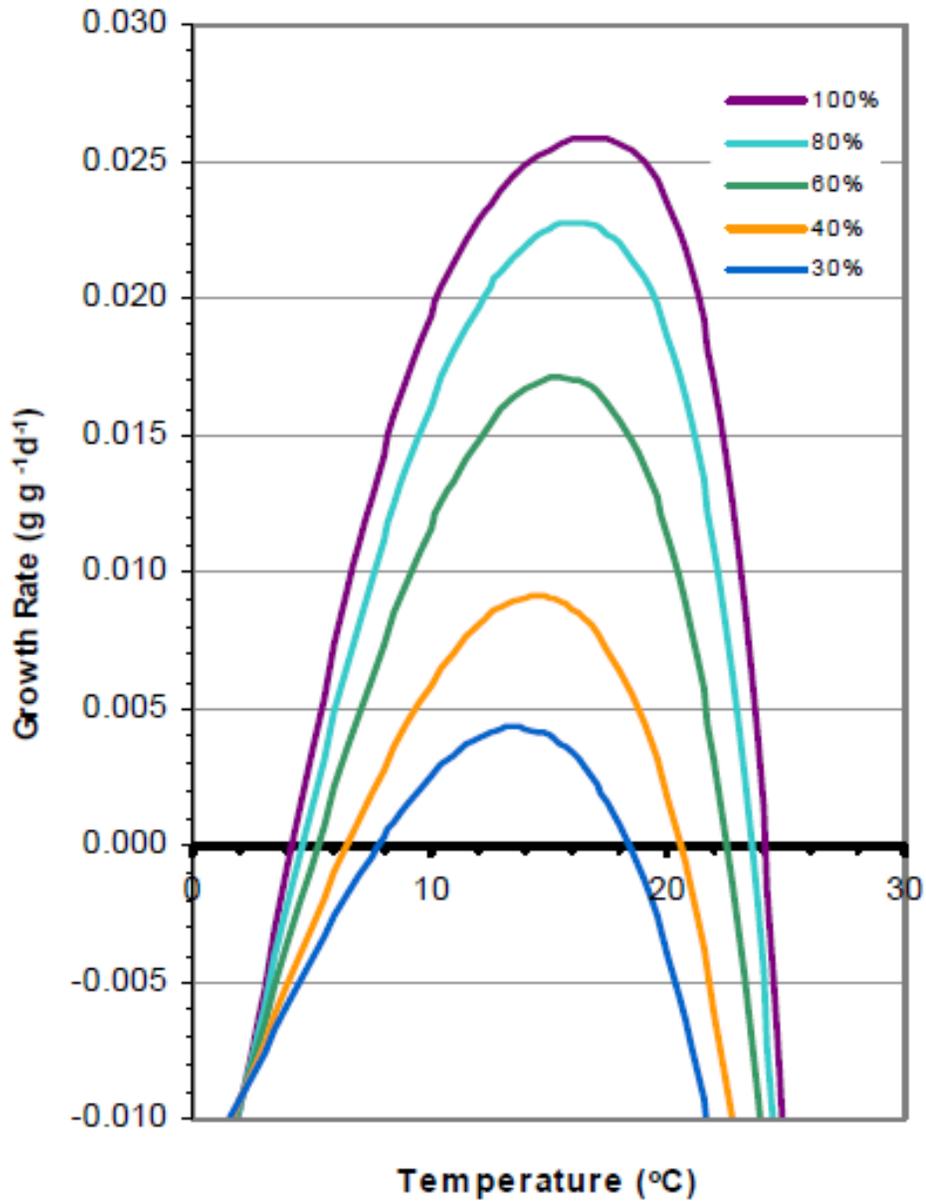


Figure 5: "Coho salmon daily growth rate as a function of temperature and daily food ration" (TAC, 2007)

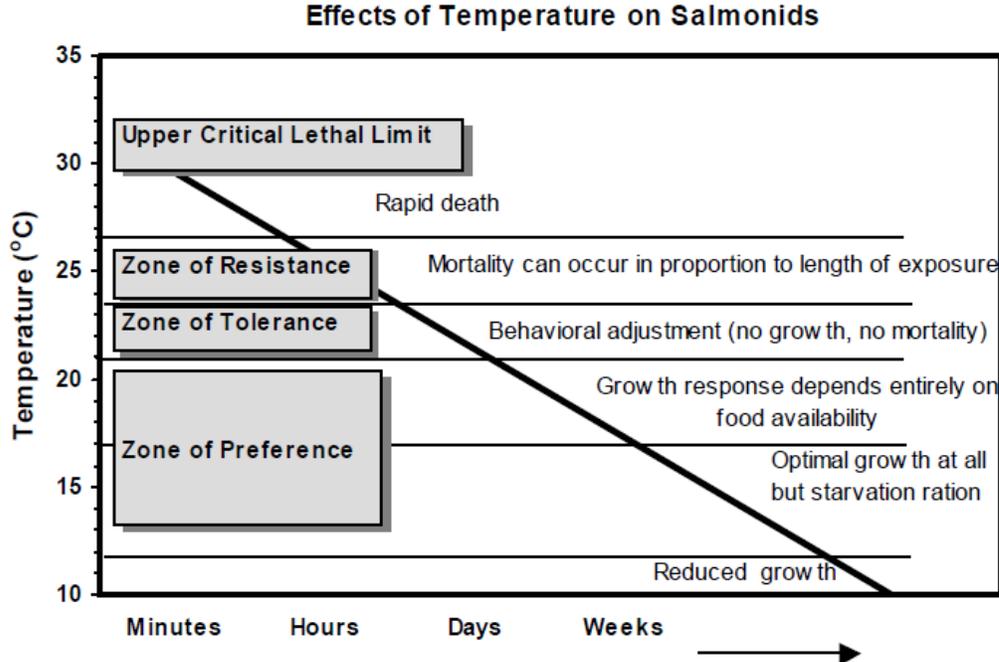


Figure 6: "Biological effects of temperature on salmonids in relation to duration and magnitude of temperature" (TAC, 2007)

Finally, the TAC Primers cover concerns with large woody debris recruitment – essential structure for “regulating the temporal, spatial character and the quantity of sediment stored within the channel zone” and providing habitat for aquatic wildlife, including anadromous salmonids (Technical Advisory Committee of the California Board of Forestry and Fire Protection, 2007). However, excessive fine organic inputs can reduce available dissolved oxygen, negatively impacting fish. The size and number of wood inputs will vary based on wildlife needs, hydrology, and other site-specific characteristics. For example, considerations for future recruitment are especially important in coastal areas of California and the Coastal Anadromy Zone. Several impacts on this key process from timber harvesting have been consistently documented and impacts to wood recruitment processes can have long recovery times (50+ years). Several BMPs are suggested in the primer and the TAC states that management for certain species which are important for large woody debris inputs (such as large conifers) may help preserve this essential function during selective harvest.

More mixed results were identified for bird, mammal, and amphibian communities in studies by Pottier (2002), Fredericksen and Fredericksen (2004), and Raffael (2006). Pottier’s study (2002) addressed the impacts of selection logging on macroinvertebrate, fish, and bird communities and found generally that selection logging “appears to cause less disruption than clearcutting and/or stand conversion,” but that impacts that are present can remain for decades.

Fredericksen and Fredericksen (2004) studied the diversity of amphibian communities following partial harvest and observed a trend for increased abundance in disturbed areas, but it was not significant. They also noted no significant difference in species richness between treatments. However, they did see increased abundances for certain species and reduced numbers of frogs compared to toads in disturbed areas. Understory cover did not differ significantly between treatments and large woody debris cover was greater in disturbed areas which may have habitat benefits for species that are dependent on snags and forest floor composition. In general, they argue that limited harvesting (23-30%) may not have significant negative impacts for amphibian communities.

Raffael (2006) echoes this sentiment to some extent, stating that disturbances can have positive and negative impacts on amphibian species. However, Raffael (2006) agrees with Burns (1972) and highlights the importance of considering multiple life stages of a given species or group of species. Impacts to adult frogs, for example, may be very different than impacts to juveniles or embryos of the same species. Raffael (2006) and Pottier (2002) also highlight the important point that while the overarching measure of diversity may not be troubling, finer scale inspections often reveal benefits for some species and negative impacts for others and depending on management goals the negative impacts may outweigh the benefits. Indeed, Raffael (2006) discusses the importance of functional diversity and looking closer at the species level impacts. Large-scale, generalized measures of diversity may not be sufficient to capture the true impacts of anthropogenic disturbances and instead may hide significant differences in functionality at the species level. Older disturbances have shown some recovery in amphibian functional diversity, but the short-term implications of these changes are important for things like invasive species establishment. Studies have shown that “communities with higher functional group diversity have been shown to be more resistant to invasion by exotic species.” As functional groups decline, niche space opens up for invasive species.

Finally, Braithwaite and Mallik (2012) highlight the edge effects produced by buffer zones around watercourses, and argue that a more “feathered” approach that creates a more gradual shift between habitat types and encourages heterogeneity in the edge zone may benefit wildlife. They also assert that this kind of management may more closely resemble the patchiness of edges created by wildfire.

## **Approaches for Riparian Stand Management**

When employing low-pressure ground equipment like feller-bunchers, many management approaches are available depending on the manager’s goals. For the purposes of this paper, the goal of reducing catastrophic fire threat is of highest importance, closely followed by the restoration of appropriate stand structures to encourage long-term resilience. Agee and Skinner (2005) and York et al. (2012) agree that some thinning and accompanying slash and surface fuel treatment are needed to

shape resilient forests. However, thinning can be done in various ways and with various outcomes. Generally, thinning is the removal of trees to reduce stand density to improve spacing, tree vigor, and tree size. However, a manager can choose to thin from above (Figure 7), removing mostly larger canopy trees, thin from below (Figure 8), removing mostly smaller understory trees, or some combination of the two (Resources, 2010).

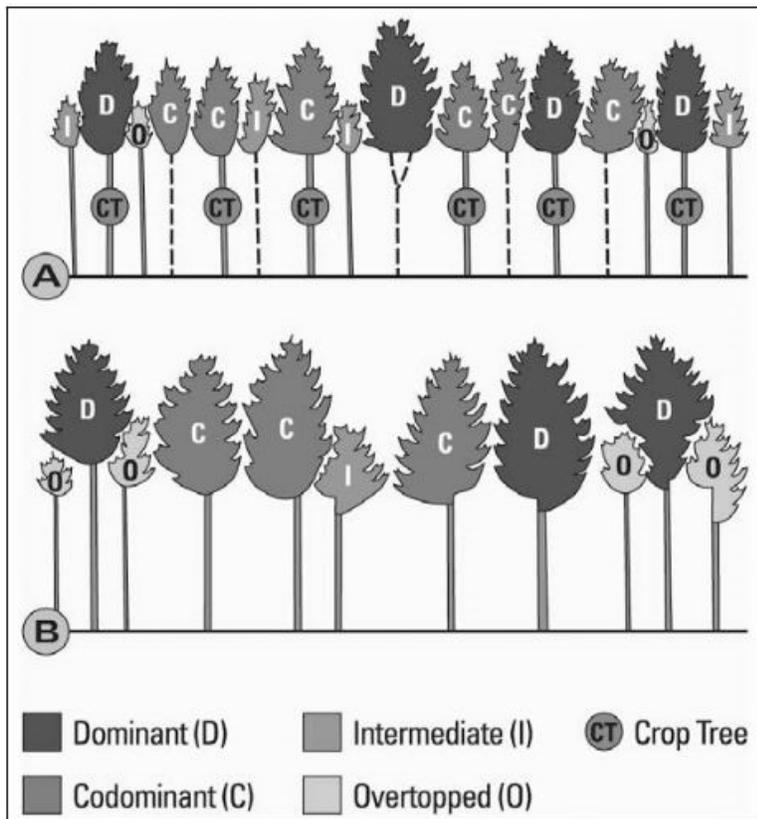


Figure 7: "The upper sketch (A) shows a coniferous stand immediately before a crown thinning... The lower sketch (B) shows the same stand about 20 years after the crown thinning..." (Resources, 2010).

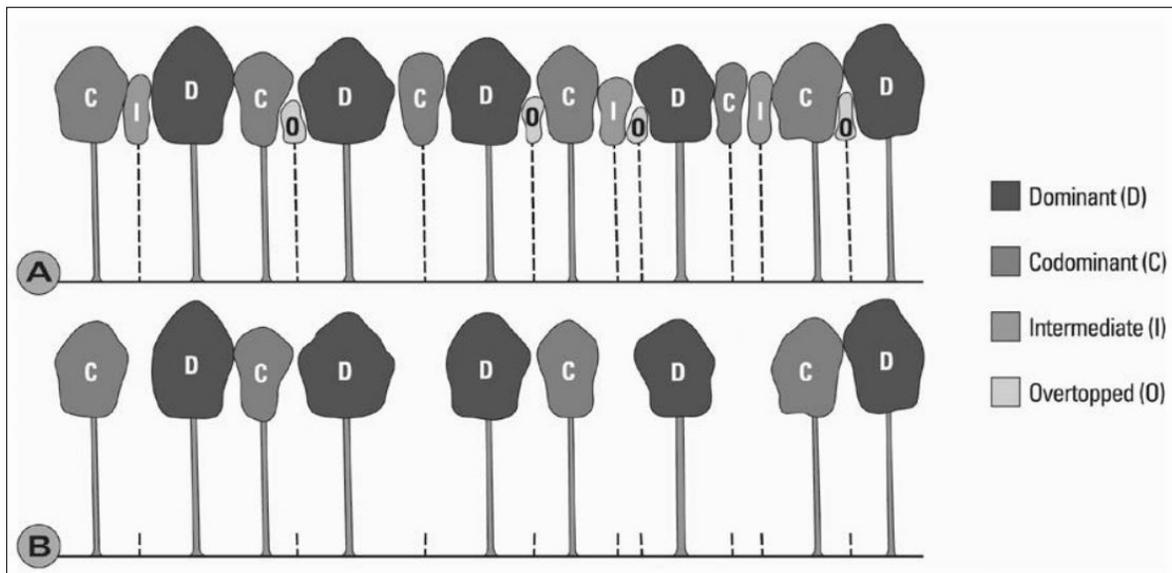


Figure 8: "How a stand might look before (A), and after (B), a low thinning" (Resources, 2010).

Agee and Skinner (2005) and York et al. (2012) suggest that thinning from below and retaining some large, fire-resistant trees is the best method of thinning for reducing fire hazard in an area. However, these studies as well as Stephens (1998) indicate that adequate treatment of surface fuels is equally if not more important for reducing fire behavior. Indeed, Stephens (1998) modeled fire behavior under various management strategies and found that landscape level surface fuel treatments such as prescribed burns following thinning significantly reduced fire behavior. Additionally, York et al. (2012) discuss the use of gap creation as a feasible means of treating fuels and more closely mimicking historical conditions. As discussed in Appropriate Post-Treatment Stand Dynamics, this kind of gap creation, provided the gaps are large enough, may contribute to successional patterns that more closely mimic historical stands.

Additionally, mastication of non-merchantable fuels has become an important component of various fuel reduction efforts. Busse, Hubbert, and Moghaddas (2014) define mastication as "a mechanical fuel treatment applied to shred, grind, mulch, mow, or chunk woody understory vegetation and small trees." When managed properly, mastication can be a beneficial practice for managing fuels in riparian areas by rearranging canopy, ladder, and standing surface fuels into a mat of masticated material while minimizing soil disturbance, maintaining key nutrients on-site, and insulating soils to changes in temperature and moisture content. Preliminary research indicates that the insulating ability of masticated materials may help mitigate some of the impacts of increased canopy opening on soil quality and fuel treatment longevity (Busse et al., 2014).

## Best Management Practices (BMPs) Identified in the Literature

This section is intended to list several BMPs that have been identified in the FPRs and peer-reviewed literature. Some BMPs may appear twice if they are present in the FPRs and identified in the literature, or if they are applicable to the preservation of different watershed processes. These BMPs address some of the key environmental concerns discussed above, but are by no means all-encompassing. Site-specific conditions will heavily influence which management strategies listed are appropriate and what (if any) additional BMPs may be needed to conduct work in WLPZs and maintain soil, water, and ecological functions.

### In the FPRs

- 14 CCR 916.9, 936.9, 956.9
  - 14 CCR 916.9(f)(2)(D) - Preferred Management Practices in the Inner and Outer Zones [ASP Rules]
  - 14 CCR 916.9(f)(3)(E) - Preferred Management Practices in the Inner Zone A and B of Flood Prone Areas [ASP Rules]
- 14 CCR Division 1.5, Chapter 4, (Subchapter 4, Article 12; Subchapter 5, Article 11; and Subchapter 6, Article 12)
  - Board of Forestry Technical Rule Addendum No. 5 – Guidance on Hydrologic Disconnection

### In Peer-Reviewed Literature

#### Soils

1. Conduct operations only in dry or frozen soil conditions, or over snow
  - a. (Resources, 2003)
  - b. (R. J. Poff, 1996)
2. Use tracked equipment
  - a. (Mattson, Baumgras, Blinn, & Thompson, 1999)
  - b. (Akay et al., 2006)
  - c. (R. J. Poff, 1996)
3. Plan a skid route with attention to minimizing soil disturbance; clearly flag the skid trail; and include the operator in the planning process to ensure implementation of management objectives
  - a. (Kreutzweiser & Capell, 2002)
  - b. (Contreras, Parrott, & Chung, 2015)
  - c. (Mattson et al., 1999)
  - d. (Lewis, 1998)
  - e. (Nitschke, 2005)
  - f. (Froehlich & McNabb, 1983)
4. Place slash on the equipment pathway to reduce soil compaction
  - a. (Rone, 2011)
  - b. (R. J. Poff, 1996)

- c. (Akay et al., 2006)
- 5. Minimize equipment passes on a single track
  - a. (Froehlich & McNabb, 1983)
  - b. (Contreras et al., 2015)
- 6. Implement equipment exclusion on areas that are steep or unstable and pre-flag these boundaries
  - a. (Resources, 2003)
  - b. (R. J. Poff, 1996)

### Water Quality

- 1. Avoid disturbance to flood prone areas and poorly drained soils
  - a. (Technical Advisory Committee of the California Board of Forestry and Fire Protection, 2007)
  - b. (Cafferata et al., 2005)
- 2. Do not store or use chemicals in riparian areas; no refueling or servicing equipment in WLPZs
  - a. (Broadmeadow & Nisbet, 2004)
- 3. Harvest on deep slash layers when possible
  - a. (Technical Advisory Committee of the California Board of Forestry and Fire Protection, 2007)
  - b. (Kreutzweiser & Capell, 2002)
- 4. Do not place slash into the watercourse or in areas where it is likely to enter the watercourse
  - a. (Resources, 2003)
  - b. (Broadmeadow & Nisbet, 2004)

### Flow and Energy Dynamics

- 1. Maintain adequate canopy cover, especially on the south side of streams
  - a. (R. J. Poff, 1996)
  - b. (Technical Advisory Committee of the California Board of Forestry and Fire Protection, 2007)
  - c. (Burns, 1972)
- 2. Maintain adequate sources of woody debris, relative to site-specific conditions and future needs
  - a. (Technical Advisory Committee of the California Board of Forestry and Fire Protection, 2007)

### Post-Harvest Forest Conditions

- 1. Employ directional felling away from the watercourse channel
  - a. (Akay et al., 2006)
  - b. (Kreutzweiser & Capell, 2002)
- 2. Use skid trails with no sharp turns when possible
  - a. (Mattson et al., 1999)
  - b. (Akay et al., 2006)

3. Treat logging slash appropriately to reduce fire hazard and protect water and soil quality
  - a. (Fahnestock, 1960)
  - b. (Stephens, 1998)
4. Consider gap creation as a management technique
  - a. (R. A. York et al., 2012)
  - b. (Hall et al., 2003)
  - c. (Messier et al., 2012)

For additional information on site-specific management guidelines, please see the 2012 VTAC report (Liquori et al., 2012).

## How Do BMPs Address Environmental Concerns?

### Minimize Compaction

Compaction is addressed through Soil BMPs 1, 2, 3, 4, and 5. Poff (1996) and the Wisconsin Department of Natural Resources, Division of Forestry (2003) both cite the importance of conducting operations on dry soils for reducing compaction. Drier soils are shown to have higher soil strength, enabling them to withstand equipment passes with less compaction. The use of tracked machines can also reduce soil impacts such as rutting and compaction because they more readily distribute pressure (Akay et al., 2006; Mattson et al., 1999; R. J. Poff, 1996). Planning a skid route, flagging the route, and discussing management objectives with the operator can reduce the amount of compaction on a site by minimizing the areas that receive machine traffic and minimizing the number of passes at a given location (Contreras et al., 2015). The study by Contreras, Parrot, and Chung (2015) indicates that this practice can be environmentally and economically sound and assists managers in managing for multiple purposes. Finally, using cut-to-length systems and leaving some slash on equipment pathways can help absorb pressure and reduce soil compaction. However, there is some discussion among researchers about the total benefit of this practice in contrast with the fire hazard this can present for some sites (Akay et al., 2006; R. J. Poff, 1996; Rone, 2011).

### Reducing Erosion and Water Quality Impacts

Erosion and water quality impacts are addressed through Water Quality BMPs 1, 2, 3, and 4 and Soils BMP 6. Equipment exclusion on unnecessarily steep (>35%) or unstable areas and flood prone areas can help reduce erosion and associated water quality impacts by minimizing disturbance on sensitive areas (Cafferata et al., 2005; R. J. Poff, 1996; Resources, 2003). Managing to retain natural drainage and flow patterns may help reduce sedimentation impacts of forestry in WLPZs by slowing the movement of sediment on the landscape and allowing some sediment to be “caught” prior to reaching the watercourse. Appropriate slash treatment prevents higher fire risk in riparian areas, prevents changes to nutrient input and dissolved oxygen in streams, and prevents additional sedimentation associated with slash entering the watercourse. Finally, avoiding storing chemicals in WLPZs or servicing equipment in WLPZs reduces

the likelihood of chemical contamination of watercourses (Broadmeadow & Nisbet, 2004).

### Maintaining Thermodynamics and Energy Structures

The maintenance of adequate canopy cover (Flow and Energy Dynamics BMP 1) is essential for physical and biological properties of aquatic systems. Specifically, maintaining stream temperatures can help minimize negative impacts to sensitive aquatic species such as anadromous salmonids (Burns, 1972; R. J. Poff, 1996; Technical Advisory Committee of the California Board of Forestry and Fire Protection, 2007). Additionally, minimizing changes in light penetration (Flow and Energy Dynamics BMP 2) can prevent significant changes in primary productivity, macroinvertebrate productivity and associated trophic impacts. Finally, maintenance of adequate canopy cover and consideration of large wood needs at a site can help maintain important habitat for wildlife by supporting snag and woody debris recruitment processes (Technical Advisory Committee of the California Board of Forestry and Fire Protection, 2007). Working to maintain much of the original canopy in WLPZs can help minimize disturbances to these aquatic functions and minimize impacts to aquatic wildlife.

### Encouraging Healthy Stand Dynamics and Biodiversity

Issues of residual stand health and biodiversity are addressed through Post-Harvest Forest Conditions BMPs 1, 2, 3, and 4. Residual stand damage can be minimized by using zero-swing equipment, using cut-to-length and forwarder systems, or planning skid trails to be relatively straight and without severe turns. These practices minimize opportunities for equipment to come into contact with residual trees and minimize difficult to maneuver situations for operators that may increase the likelihood of equipment striking a tree. Finally, directional felling away from watercourse channels can help ensure that debris does not enter the watercourse and that equipment is not needed near or in the channel.

## Ongoing Research

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“EMC-2017-006: Tradeoffs among riparian buffer zones, fire hazard, and species composition in the Sierra Nevada” (R. York, 2017)

The Board’s Effectiveness Monitoring Committee (EMC) funded this proposal in 2017. The proposal justification detailed several of the issues presented above, including: present deviations from historical fire regimes, perceived barriers to harvest in riparian areas, increased fire threat in these areas and potential adverse effects to water quality and riparian function.

Figure 9 shows images of the work conducted at Blodgett Forest Research Station within Class II WLPZs, including treated and untreated stands.



*Figure 9: Treated (Left) vs. untreated (Right) WLPZ at Blodgett Forest Research Station.*

The Board granted this project experimental designation until 2032 to allow a full investigation of the impacts of heavy equipment in the WLPZ and the potential benefits of increased management. The four treatment types include:

- 1) Control – no harvesting or fuel treatment
- 2) Status Quo – selective removal of canopy trees with no equipment entry and directional felling
- 3) Fire Severity Reduction – thin from below and follow with treatment of surface fuel
- 4) Fire Severity Reduction + Small Gap Restoration – the same treatment as described above, but with small canopy gap creation to facilitate growth of shade-intolerant species

Response variables:

- 1) Light Availability
- 2) Stream Temperature
- 3) Understory Vegetation and Forest Structure Dynamics
- 4) Snag and Coarse Woody Debris Dynamics
- 5) Survival and Growth of Planted Native Conifer Species
- 6) Soil Strength and Soil Moisture

Preliminary data from the primary investigator, Dr. Rob York, has not yet detected significant sedimentation in watercourses after heavy equipment use when BMPs are followed (R. York & Roughton, 2019). The long-term goal of the study is to inform decision-making related to fuel treatments in WLPZs and the inclusion of an adaptive management framework when considering the use of certain heavy equipment in WLPZs. However, the use of heavy equipment in WLPZs as an in-lieu practice is not incumbent on project completion; more widespread use during project implementation would increase opportunities to monitor and better quantify environmental impacts relative to fire hazard reduction benefits.

### Green Diamond Resource Company “Riparian Canopy Modification Experiment” (Diller et al., 2018)

This project took place on the South Fork of Ah Pah Creek in Humboldt County and addresses the tradeoffs between management for water temperature, large wood, sediment filtration, and productivity in aquatic ecosystems. The researchers reduced left bank riparian cover to 50% in accordance with a THP and collected data on water temperature,

canopy closure, and amphibians and fish before and after treatments. Their experimental design allowed for sampling to occur upstream of the treatment site, at the treatment site, and downstream of the treatment site.

The researchers found that natural variation in canopy structure resulted in decreased heterogeneity in gaps at the treatment site, rather than timber harvest activities. Additionally, water temperatures were found to have increased, but stayed within a biologically sound range that supports salmonid production. Finally, analysis of the animal metrics taken (weight and length) is currently underway and an additional report detailing the impacts on the Coastal Giant Salamander and fishes will be released soon.

“EMC-2018-006: Effectiveness of Class II watercourse and lake protection zone (WLPZ) Forest Practice Rules (FPRs) and Aquatic Habitat Conservation Plan (AHCP) riparian prescriptions at maintaining or restoring canopy closure, stream water temperature, and primary productivity” (Bladon, Segura, House, & Coe, 2018)

The Board’s Effectiveness Monitoring Committee funded this proposal in 2019. The proposal aims to address whether the FPRs and Aquatic Habitat Conservation Plans for headwater streams successfully maintain appropriate aquatic characteristics such as temperature, flow volumes, stream metabolism, and canopy closure, and how do these parameters influence stream temperature, dissolved oxygen, and primary productivity particularly during critical summer low flows. This project will provide future analysis on direct water quality and productivity impacts which are essential for supporting anadromous fishes in California.

## Conclusion

Wildfires in California and the western United States are increasing in size and severity and are resulting in adverse effects to water quality and aquatic habitat. Evidence has suggested that limitations on timber harvest and other forms of management in riparian corridors may be a contributing factor to these changes in fire regimes. Scientific literature shows that this phenomenon is not simply anecdotal – that disturbance regimes in riparian areas no longer mirror historical regimes. Changes to the function of riparian corridors present unique challenges and threats because of their linear nature and ability to connect the landscape. This connectivity can result in increased fire spread if riparian vegetation is not managed and can spread water quality impacts to downstream locations. Additionally, management regulations in riparian corridors can restrict or reduce the effectiveness of landscape level treatments such as fuel breaks, resulting in potential impacts to upland areas and increased fire spread. Historically, riparian corridors have experienced fire return intervals and severities similar to upland stands. Current riparian and upland stands both differ significantly from their historical counterparts, but riparian areas have deviated more significantly in composition and density than upland stands, putting them at greater risk for severe wildfire in some parts of the state. However, when managed appropriately, restoration of these areas through limited timber harvesting and fuel treatment can result in benefits for wildlife species by preventing stand replacing fires.

California's diverse landscape means that management for beneficial uses in riparian corridors can include different methods and considerations in different forest types. Thus, management in riparian corridors is highly site-specific. Site-specific management that addresses possible environmental impacts to soil quality, water quality, and riparian and aquatic communities that may result from management activities is important for preserving key ecosystem functions. If not managed correctly, heavy equipment use in WLPZs can result in soil compaction, stream sedimentation, reduced site productivity, changes to aquatic energy dynamics, changes in flow, light availability, stream temperature, and impacts to botanical resources and wildlife. However, studies have indicated that when certain BMPs are followed, impacts from heavy equipment use in WLPZs can be significantly reduced. Some of these BMPs include measures to minimize soil impacts, water quality impacts, and considerations for post-treatment stand dynamics and productivity.

Generally, the consensus on thinning for fuel reduction is to thin from below and include surface fuel treatment, but some researchers have noted the importance of gap creation dynamics to support stand composition that more closely mimics historical stands in terms of age, size, shade preference, and maintenance of fire exclusion and high severity fire areas to promote sensitive and rare species protection. This kind of management under the current FRPs is limited in scope and impact relative to other forms of timber harvest. A justification by the RPF preparing the plan is required to implement these practices in WLPZs and suggested BMPs further limit the treatable area under consideration based on site-specific conditions and concerns. The Board

supports this implementation, compliant with the current FPRs, and continues to investigate the impacts and potential benefits of heavy equipment use in WLPZs in California to combat catastrophic wildfire. Additional implementation in accordance with the FPRs will allow for increased monitoring opportunities and inform the Board regarding best practices and the appropriate scope of heavy equipment use in WLPZs.

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