# EASTSIDE TIMBER HABITAT EVALUATION PROJECT

## STUDY DESIGN TO EVALUATE FRAMEWORKS FOR APPLYING RIPARIAN HARVEST RULES ALONG TYPE S AND TYPE F STREAMS IN EASTERN WASHINGTON BASED ON FPHCP OBJECTIVES AND PERFORMANCE TARGETS

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# Executive Summary

This document presents the study design for the Eastside Timber Habitat Evaluation Project (ETHEP). ETHEP was initiated to develop framework(s) for applying riparian harvest rules along Type S and Type F streams in eastern Washington that are based on the Forest Practices Habitat Conservation Plan (FPHCP) objectives and performance targets. The 2006 FPHCP was adopted to provide protection for aquatic resources including salmonid fish, stream-associated amphibians and water quality while providing opportunities for timber harvest, and flexibility in harvest unit design. The measures in the FPHCP riparian strategy are intended to restore and maintain riparian and instream processes that create and enhance aquatic habitat, with emphasis on large wood recruitment and shade retention (WDNR 2005). The study will examine and develop alternative(s) to the current Timber Habitat Type (THT) system using GIS analysis of existing geospatial datasets and validate and refine the alternative framework(s) for their accuracy in characterizing eastern Washington riparian forests using data collected in the field. This study design follows Alternative 2 of the scoping document. Alternative 2 was recommended above other listed alternatives by the Scientific Advisory Group Eastside (SAGE).

ETHEP will be accomplished in two phases. Phase 1 involves three steps that will provide information necessary for initiating Phase 2, which will contain two steps. At the conclusion of Phases 1 and 2, a follow-up discussion and appraisal of the results with SAGE and CMER will be scheduled to estimate the utility and practical applicability of the framework(s). If necessary, the recommendations provided by SAGE and CMER will be incorporated into the framework. Step 1 will entail a desktop GIS analysis to integrate existing biological and physical spatial datasets related to riparian forest composition, structure, and environment across eastern Washington. This step includes the organization, appraisal, and possible combination of publicly available datasets based on their ability to characterize the study area's site, vegetation, and landscape features. The characteristics important for relating a framework to the FPHCP objectives to restore and maintain riparian and instream processes were identified in a review of relevant literature, described below. The habitat classification method best suited for the data available will be determined after Step 1 (dataset analysis).

Step 2 of Phase 1 will involve the development of the classification framework using one or more of the habitat classification methods described in the Framework Development section. Any portions of the study areas lacking coverage or details of the characteristics important for framework development will also be identified for data collection during Phase 2.

Step 3 of Phase 1 will use simulation modeling to estimate stand development over time using publicly available field data sets. This initial evaluation to estimate stand development over time will use the publicly available datasets appraised and catalogued in Phase1, step 1. Data will be stratified by the classification units (habitat categories) developed in Step 2. Simulation outcomes will be used to evaluate similarities and differences in each classification unit’s projected endpoints and will inform the potential refinement of the classification units. Once the frameworks are refined to the most parsimonious grouping of classification units, SAGE and Cooperative Monitoring Evaluation and Research (CMER) will be consulted for their expert input on the potential for framework utility in the field and application to meeting FPHCP functional objectives, and for recommendations for further refinement.

Phase 2 will involve targeted field surveys to 1) remedy any gaps or inconsistencies in the publicly available datasets found in Phase 1 and 2) test the ability of the frameworks to characterize riparian areas supportive of project objectives. Phase 2 will be completed in 2 steps.

Step 1 of Phase 2 will entail the actual field data collection. Several potential methods for field data collection via remote sensing may also be employed. Specific protocols for field data collection will be developed at the conclusion of Phase 1.

Step 2 of Phase 2 will entail using the field data to test and refine classification units developed in Phase 1. Methods for the assessment of classification accuracy will follow those described by Goebel et al. (2001) which uses a variation of canonical correspondence analysis to confirm field-based classification and to measure the level of distinctness of each classification unit, described in more detail below. Simulation modeling will again be used to evaluate similarities and differences in each classification unit's projected endpoints and will inform the potential refinement of classification units. However, for Phase 2, a larger suite of modeling tools will be explored (e.g., ZELIG-CFS, LANDIS, Forest Planning and Projection System), described in more detail in the *Accuracy Assessment and Refinement* section of Phase 2, step 2. Once the validated frameworks are again refined to the most parsimonious grouping of classification units, SAGE/CMER will again be consulted for their expert input on the potential for framework utility in the field and application to meeting FPHCP functional objectives, and for recommendations for further refinement.

## Project Overview

The *Eastside Timber Habitat Evaluation Project* (ETHEP) is being performed and conducted under the authority and guidance of the Cooperative Monitoring Evaluation and Research (CMER) Committee. In 2001 the Washington State Legislature officially adopted new Forest Practices Rules approved by the Washington Forest Practices Board (WDNR 2001) that are now in effect and described in federally approved Habitat Conservation Plan (WA Forest Practices HCP 2005). These rules had previously been adopted temporarily via an emergency rule in 1999 based on the recommendations of the Forests and Fish Report (FFR; WDNR 1999). The FFR was a multi-stakeholder effort to improve forest practices and the protection of aquatic and riparian habitats on non-federal forestlands regulated by WDNR under Washington's Forest Practices Act. The CMER Committee was formed to oversee and perform research in support of an Adaptive Management Program (AMP) including this study.

Washington's Forest Practices Rules for non-federal forestlands in eastern Washington uses a Timber Habitat Type (THT) system to apply riparian rule prescriptions along fish-bearing (Type

S and Type F) streams (WAC 222-30-022). This system defines THTs according to three elevation zones: <2500 feet ("Ponderosa Pine"), 2500-5000 feet ("Mixed Conifer"), and >5000 feet ("High Elevation"). The riparian harvest rules specify different leave tree requirements for each THT. For instance, thinning of the riparian management zone within the mixed conifer (2500 – 5000 feet) habitat type requires a higher minimum basal area (70 – 110 square feet per acre depending on site index) compared to the ponderosa pine (< 2500 feet; 60 square feet per acre regardless of site index). Other rules for preferred species and tree distributions are further described in the WAC 222-30-022. This system is intended to reflect differences in silvicultural needs within these zones and differences in riparian functions provided. ETHEP was formed to develop alternative(s) to the THT system, but it will not directly test the effectiveness of the current THT rules or associated prescriptions.

Prior study, however, indicates that elevation zones alone do not fully account for the multiple factors that drive riparian forest stand development. Phase II of the Eastern Washington Riparian Assessment Project (EWRAP; Schuett-Hames, 2015) determined potential climax species for 103 riparian sites in eastern Washington using the classification criteria established by Cooper et al. (1991) and Kovalchik and Clausnitzer (2004) and found that the distribution of riparian forest vegetation "series" does not necessarily align with the names of the THT elevation zones. By extension, elevation is likely not the only factor that can be used to determine the specific silvicultural prescriptions best suited for riparian areas or the ecological functions of riparian systems.

The purpose of ETHEP is to develop a framework for applying riparian harvest rules along Type S and Type F streams in eastern Washington based on the functional objectives and performance targets (Schedule L-1, Appendix N) of the Forest Practices Habitat Conservation Plan (FPHCP) (FPHCP, 2005). For the purpose of this study, a framework is generally defined as a system that can be used to inform and guide management prescriptions that support the goals and objectives of the FPHCP (the current THT system is one example). ETHEP is included in the Eastside Type F Riparian Rule Tool Program research needs presented in the 2021-2023 Biennium CMER Work Plan. This study will also be used to provide information for answering the Critical Question asked by the Eastside Rule Group: *Will the application of the prescriptions result in stands that achieve Eastside FPHCP objectives (forest health, riparian function, and historical disturbance regimes)?*

The ETHEP study design in this document is guided by a scoping document approved by the Scientific Advisory Group Eastside (SAGE), CMER, and Policy. An initial draft ETHEP scoping document was prepared in October 2015 but was not reviewed by CMER or transmitted to Policy. In April 2016, CMER ranked ETHEP as the second priority for the Adaptive Management Program (AMP) to be funded by the Mid-year CMER Project List. A sub-group was formed in August 2018 to update the scoping document based on feedback from subject matter experts. The updated scoping document was approved by SAGE in September 2020, followed by CMER in March 2021, and then by The Timber Fish and Wildlife Policy Committee (Policy) in June

2021 (ETHEP 2021). Following Policy's approval, a project team of technical experts was formed to develop this ETHEP study design based on the approved scoping document.

Consistent with the Scoping Document, ETHEP has two study objectives:

1. Develop a framework for applying riparian harvest rules in eastern Washington based on the FPHCP functional objectives and performance targets (Schedule L-1, Appendix N).

2. Test the framework(s) for characterizing eastside riparian forests using data collected in the field.

ETHEP will achieve these study objectives by answering four critical questions:

Objective 1:

1. What type and quality of data are needed to accurately characterize and differentiate riparian stands, their development in eastern Washington, and their associated riparian functions?

2. Do existing datasets (alone or in combination) provide the necessary information to accurately characterize and differentiate riparian stands, their development, and associated riparian functions?

3. If existing datasets do not provide the necessary information to differentiate riparian stands, their development, and associated riparian functions, how can this additional information be acquired and utilized?

Objective 2:

1. Does the framework accurately characterize riparian forests in the field based on characteristics important for meeting FPHCP functional objectives and performance targets?

There are several things this project will not do. Specifically, this ETHEP study <u>will not</u>:

- Test the effectiveness of the current THT system (the current rules), associated leave tree/basal area requirements, or preferred species list for Type S and Type F waters in eastern Washington.
- Test or develop alternate harvest rules (i.e., leave tree/basal area requirements and preferred species list) for eastside RMZs along Type S and Type F waters.
- Develop criteria or desired outcomes for rules applied to eastside RMZs along Type S and Type F waters.
- Develop a framework (classification system) intended for identifying habitat types along Type N streams in eastern Washington.

# Prior Investigation

The current harvest regulations for eastern Washington state's forest lands adjacent to fish-bearing (Type F) rivers and streams managed under the Forest Practices Rules and Habitat Conservation Plan (FFR and FPHCP) follow a timber habitat type (THT) system whereby the landscape is divided into three elevational zones. These elevation zone delineations have been attributed to Franklin and Dyrness (1973) description of eastern Washington forest covertype distributions they associated with historical disturbance, temperature, and moisture regimes that naturally occur at low (<2500 ft), mid (2500-5000 ft), and high elevation (>5000 ft) (CMER 02-025; FFR, 1999). The current regulations were approved and implemented in 1999 by the Washington State Forest Practices Board following the recommendations of the Forests and Fish Report in 1999 (WDNR, 1999).

Since then, two studies conducted by CMER have provided some evidence that the application of riparian harvest rules under the current THT system may not satisfy the FPHCP functional objectives and performance targets. The first study is a report by Schuett-Hames (2015; EWRAP Phase 2) that found multiple ponderosa pine stands in the mixed conifer zone and vice-versa on several riparian timber lands covered by the FPHCP. This includes approximately 3.2 million acres of non-federal, non-tribal forest lands in eastern Washington, comprised of individuals and families who own small forest parcels to large holdings owned and/or managed by private corporations and public agencies. Further, when the researchers applied forest series classification system methods derived from Cooper et al. (1991) and Kovalchik and Clausnitzer (2004) to the 103 sampled stands and compared it to the THT classification system. The result was a low level of agreement in the ponderosa pine (7.9%) and high elevation habitat types (33.3%). Schuett-Hames (2015) speculated that low level of agreement might be because the rules are based on concepts developed for upland forests. Other potential causes included past management practices and the absence of the ponderosa pine category in the Kovalchik and Clausnitzer (2004) classification system. Schuett-Hames (2015) concluded that the conceptual basis for the variation in climatic conditions and disturbance regimes is sound. However, the authors recommended an evaluation of 1) the extent to which the THTs correctly identify and delineate climatic conditions, environmental factors (e.g., moisture regimes), and disturbance regimes in riparian areas; and 2) whether the target prescriptions applied in the THT zones will lead to healthy, resilient riparian stands that preserve the desired riparian functions (e.g., FPHCP objectives).

The second study was Ceder et al. (2020; Eastside modeling Effectiveness Project (EMEP)) which used data from the EWRAP study to model how the current stands might respond to the THT target prescriptions over time (suggestion 2 from Schuett-Hames (2015) for validation). However, an investigation into the extent of how well the THTs identify and delineate climactic and environmental factors (suggestion 1) and their variation was not completed. Instead, the purpose of EMEP was to use modeling to evaluate the effectiveness of Eastside rules and alternatives. However, in doing so, Ceder et al. (2020), suggest that the variability observed in their evaluation of the effectiveness of the Eastside rules may have obscured the differences observed in the conditions among the THTs, and prescriptions. Ceder et al. (2020) found that thinning in the inner zones (area 30-75 feet from the stream) under the THT prescriptions led to a reduction in growth rates of residual trees relative to unmanaged stands. This result is counter-intuitive to desired resource objectives, which aim to increase growth by reducing competition. Next, the authors concluded that the models used in the EMEP did not distinguish between the elevational zones for timber habitat types. They suggest that the THT strata were less representative than expected if ecological plant associations were used. The stratification of the data into regulatory zones for the analysis may have increased the variability between sites that was observed, thus obscuring the differences among conditions.

At the time of the elevational band THT adoption, speculation of their insufficiency was noted in the 2002 Cooperative Monitoring, Evaluation and Research (CMER 02-205) document package "A review and synthesis of available information on riparian disturbance regimes in eastern Washington." This document states that the Forests and Fish Regulations (FFR) defined these elevational bands and accompanying cover types based on the theory that elevational zones define different moisture and temperature regimes that lead to climatic adaptive species (ponderosa pine, mixed conifer, high elevation conifers), as posited by Franklin and Dyrness (1973). However, Franklin and Dyrness (1973) also caution that the use of a zonal classification scheme (e.g., THTs) should consider several caveats, most relevant to riparian zones:

> "Zones may occur as sequential belts on mountain slopes, but more often they interfinger, with each attaining its lower elevational limits in valleys and its highest limits on ridges; as a consequence, the zones along the slopes of a narrow valley can be reversed from their otherwise altitudinal relationship."

Similarly, in an analysis of landscapes of northern Idaho and eastern Washington from the standpoint of potential "climax" communities, (i.e., vegetation that would develop in the absence of disturbance), Daubenmire (1980) concluded that microclimates controlled by topographic features allows vegetation characteristic of subalpine environments to descend locally to very low altitudes, and vice-versa. From his observations and analysis, he posits that the significance of elevation in the northern Rockies has very little ecological significance.

## Literature Review

The following is a brief review of the literature describing the factors driving different forested riparian functions relevant to FPHCP functional objectives and performance targets (shade, large wood and litter inputs, sediment, and nutrient retention), literature addressing factors important to riparian forest health, and literature describing important disturbance factors. This review is intended to provide context for ETHEP and its role in informing the Eastside Rule Group Critical Question, Will the application of the prescriptions result in stands that achieve Eastside FPHCP objectives (forest health, riparian function, and historical disturbance regimes)? Literature relevant to methods is included in the Methods sections. A more thorough and comprehensive review developed with the direction and input of SAGE reviewers can be found in Appendix I.

### *Shade*

Canopy cover provides shade for streams which decreases the amount of incoming incident radiation and regulates stream temperatures (Bescheta et al., 1987). Temperature regulation is important for sensitive salmonid fish species that require cooler waters and shade is often the primary function assessed when developing state regulations in the western U.S. (Groom et al., 2011; Groom et al., 2018; Teply et al., 2014). The importance of shade and cooler in-stream temperatures for fish habitat have been thoroughly investigated and results from multiple studies show that migrating salmonid species are most active when stream temperatures ranged between ~3 -20°C, with lethal stream temperatures for salmonids occurring between 22-26°C (Bjornn & Reiser, 1991; Chapman & Bjornn, 1969; Ebersole et al., 2001; Sullivan et al., 2000). Streamside shade will likely become even more critical with the predicted increases in air temperature over the next century (Mantua et al., 2010).

While stream temperature is initially reflective of moisture source (snowmelt, liquid precipitation) and watershed subsurface soil characteristics, as water flows downstream and into higher-order streams, the net rate of temperature gain or loss is the additive sum of incident radiation, evaporation, conduction, and advection (Brown, 1983; Beschta et al., 1987). Beschta et al. (1987) present evidence that solar radiation inputs are of the highest importance to the net heat exchange rate per unit area of the stream compared to other factors. Within the net heat exchange calculation, heat release from evaporation generally cancels out the heat gained from warm air temperatures (convective and advective heat transfer). Thus, temperature fluctuations are expected to be more severe in less-shaded/more-exposed streams. This theory has been supported by many experimental field, and simulation (DeWalle, 2010) studies showing evidence that canopy cover reduction leads to a significant increase in peak summer stream temperatures primarily due to the increase of incoming solar radiation (Beschta & Taylor, 1988; Sridhar et al., 2004; Gomi et al., 2006).

Feld et al. (2018), in a literature review of stressors in river ecosystems, concluded that while a buffer width of 30 m on either side of the stream can maintain in-stream temperatures relative to fully forested watersheds, these results were dependent on stream size. The most effective shading prescriptions for maintaining stream temperatures were for streams < 5 m in width. Moreover, they derived from studies by Collier et al. (2001) and Macdonald et al. (2003) that increasing buffer width through restorative planting correlated with reduced stream temperatures, especially in headwater streams. Further, thinning operations that reduce streamside shade not only increase local stream temperatures but have also been shown to increase downstream maximum temperatures and thermal variability in second-growth redwood forests of northern California (Roon et al. 2021). The results of these studies suggest stream size and buffer length are also important characteristics along with canopy cover percentage to consider when thinning within the riparian management area.

### *Large wood (LW) and litter*

The presence of large wood (LW) in streams is important to create pools, regulate flow, and provide a slow pulse of nutrients that help create and maintain salmonid habitat (Harmon et al.

1986). Sievers et al. (2017), in a global meta-analysis of the effects of riparian alteration on trout populations, found the most positive response of trout populations was with increasing in-stream LW and exclusion of livestock from the riparian area. Their results showed evidence that increasing in-stream LW, and litter recruitment may attract fish as opposed to increasing local populations.

Production and recruitment of LW into streams can vary between watersheds and multiple studies have attempted to identify the drivers of LW production with varying results. Benda et al. (2003), for example, present a quantitative framework for calculating the long-term wood mass balance for riparian zones. The framework includes numerical expressions for punctuated forest mortality by important drivers they identify as fire, chronic mortality and tree fall, bank erosion, mass wasting, decay, and stream transport. This framework can be applied to different regions and watersheds by adjusting parameter values to make predictions of the importance of landscape factors (e.g., climate, topography, basin size) on wood recruitment and abundance in streams for a given area. Depending on the region or landscape for which the framework is being applied, less common but more locally important disturbances such as ice storms, ice breakage, and wind throw can also be incorporated. This study and the framework developed illustrate the diversity of processes for wood recruitment, transport, and decay. The relative importance of each wood recruitment mechanism, and the fate and transport of the in-stream wood, is dependent on the level of variation observed in the environmental, management, and vegetation factors of a particular area of interest. Thus, frameworks such as the one developed by Benda et al. (2003) are helpful in identifying the relative importance of these recruitment processes and their relationship with local landscape factors.

A Review of the Available Literature Related to Wood Loading Dynamics in and around Streams in eastern Washington Forests was developed for CMER (CMER 03-308, 2004). In this review, the researchers sourced 14 references with quantitative and/or descriptive information relating to the correlation between wood volume and/or pieces of wood in streams and the adjacent riparian community. The authors conclude that while the literature is incomplete, there were several significant correlations between LW in streams and riparian zone stand characteristics. For unmanaged (defined as unlogged and un-roaded) sites in Washington, researchers reported positive correlations between the volume of LW in streams with adjacent riparian zone mean tree height ($P<0.001$), mean tree diameter ($P<0.001$), and mean basal area ($P<0.001$). Positive correlation was found between the number of LW pieces and basal area ($P<0.007$) but not between other characteristics of vegetation in the adjacent riparian area. However, when regression analysis was performed on LW piece quantity with the core zone (30 ft beyond bankfull width), a significant positive correlation was found with the density of trees in the core zone ($P<0.001$, $R^2 = 0.45$) and core zone basal area/acre. Relative to managed riparian areas, streams adjacent to unmanaged riparian areas had significantly higher LW volume. The most relevant sources of these results listed in this review were from Fox (2001), Chesney (2000), Camp et al. (1996), and Knight (1990). Two other studies (McDade et al., 1990; Fox, 2003) show evidence that as much as half of the wood found in the streams could not be attributed to the adjacent, designated riparian areas either migrating from upstream or sourced from outside the boundary of the riparian management area. These results suggest that further studies of LW drivers should focus on basin-wide study areas.

Multiple studies have also investigated the effects of timber harvest under varying riparian management zone prescriptions on LW recruitment. Specific to eastern Washington, Schuett-Hames and Stewart (2019) found that riparian management zones under the current standard shade rules (SR) for fish-bearing streams in the mixed conifer habitat type (2500 - 5000 feet elevation) had an average of four times more LW recruitment than unharvested reference sites ten years post-treatment. Proportionally, SR sites also had a higher percentage of LW recruitment from greater distances to the stream. These results suggest that while treatment of SR sites was intended to increase resistance to disturbances such as fire and disease, it also increased the susceptibility to windthrow and thus higher mortality relative to reference sites five years post-harvest. However, this was a short-term study (10 years) and the authors noted that LW recruitment is a process that can change over decadal time scales and recommended follow-up monitoring.

Another function of the riparian zone is the input of nutrients and habitat development from leaf litter. However, there appears to be a lack of experimental studies in the literature investigating the factors affecting litter delivery into streams. Bilby and Heffner (2016) used a combination of field experiments and modeling to estimate the relative importance of factors affecting litter delivery from riparian areas into streams of western Washington in the Cascade Mountains at high and low elevations. Their results showed that when the slope of the riparian area increased from 0º to 45º, the width of the litter-contributing area increased by 71-95%. This was also dependent on stand age, with mature forests, on average, showing a 35% greater contributing area than sites dominated by younger trees. The larger contributing area in mature forests was attributed to the mature stands having taller trees than the young stands (i.e., taller trees increase the contributing area). Bilby and Heffner (2016) concluded that slope, stand structure, and tree height are the most important factors in determining the effective buffer width for in-stream litter input potential.

Other than stand structure and topography, another study shows evidence of species composition as a factor affecting litter delivery into streams. Hart et al. (2013) compared the difference in litter delivery into streams between riparian zones dominated by deciduous (red alder) and coniferous (Douglas-fir) tree species in western Oregon. They found that litter input into streams was significantly higher in grams per meter per year for riparian forests dominated by deciduous forests (red alder) than for riparian forests dominated by coniferous species (Douglas-fir). The timing of the inputs also differed, with the strongest differences occurring in November during autumn peak inputs for the deciduous forests. Lateral litter movement in the riparian area increased with slope for deciduous riparian forests throughout the year, and only in the spring and summer months for coniferous forests.

Overall, most of these studies point to riparian forest productivity (e.g., tree height and tree density), slope, and species composition (deciduous vs. coniferous) as the most important drivers of organic matter (LW and litter) input into streams. The results of these studies suggest that as productivity and area of watershed increases, so does the potential for recruitment. Also, as the slope of the watershed increases, the contributing distance of organic matter to the stream increases. However, several of these studies show that the mechanisms important for estimating LW recruitment (disturbance type and severity) depend on other characteristics such as stream size, channel confinement, and management prescription history. Our interpretation of this literature suggests that the potential of LW and litter recruitment into streams can be increased by allowing basal area and large tree density to increase and by extending buffer widths relative in areas with higher slope.

### *Sediment and nutrient inputs*

The function of riparian areas to regulate and filter the flow of sediments into streams is essential not only for water clarity and pool formation but also because sediments can carry nutrients and pollutants with them (Cooper et al., 1987; Hoffman et al., 2009; Polyakov et al., 2005). Depending on the landscape context of the riparian area, for example, adjacent uplands used for agriculture or industry, the relative effectiveness of the riparian buffer on sediment and nutrient transport can differ greatly.

In the Pacific Northwest basin, geology, hydrologic/climatic regimes, stream order, position in the landscape, and channel material can all influence the supply and flux of sediment from direct and indirect effects of timber harvest. This literature review found that hillslope and vegetation cover were the main controlling factors of sediment delivery to streams. For example, Bywater-Reyes et al. (2018) found that the variation of sediment yields over 60 years in the H.J. Andrews experimental watershed in the western Cascade Range of Oregon was explained mainly by the degree of slope in the watershed. This suggests that watersheds with high slope variability may have higher variability in sediment yield following disturbance (e.g., harvest). Similarly, in an experimental analysis of factors affecting sediment transport into streams of rangeland systems, Hook (2003) discovered that slope and vegetative cover in the riparian zone were the strongest factors affecting sediment retention. Buffer widths of > 6 m effectively retained 94% - 99% of sediments when the buffer consisted of dense vegetation cover. The type and height of the vegetation present was less important than biomass, cover, and density. Sediment input in this study was highest for sparsely vegetated streams with narrow valley widths and steep slopes.

Natural disturbances such as fire can also heavily influence sediment and nutrient delivery into streams. The increase in sediment and nutrient flux into streams post-fire can vary depending on the severity of the fire and the subsequent weather conditions. The geomorphology of the landscape can also compound or ameliorate the effects of fire. For example, Crandall et al. (2021) found a 2,000-fold increase in sediment flux and a 6,000-fold increase in particulate carbon and nitrogen flux in streams of a semi-arid forested watershed of Utah that was affected by a mega-fire followed by an extreme precipitation event. However, regardless of fire severity or burned vs. unburned, a watershed modified for agriculture or urbanization showed an overall higher nutrient concentration further exacerbated by the fire/precipitation event. This study suggests that riparian zone management should also consider its proximity to agricultural and urban land use projects. In an anthropogenic shared watershed, reducing the potential for high-severity fire may be more important than in “natural” watersheds.

### *Riparian Health*

Silvicultural treatments can improve resistance to insects and disease, structural development and influence successional pathways. When appropriately applied, stand thinning can reduce susceptibility to insects, disease, and fire, and increase the diameter growth rate for large trees (Fiddler, 1989; O'Hara, 1988; Zhang et al., 2013). The prescriptions can vary depending on region and objectives (e.g., fire resistance, biodiversity, growth). Targets for the inner and outer zones of the eastern Washington RMZs incorporate structure and density to theoretically support the health and development of the riparian stand and protect stream function (FPHCP, 2005, chapter 4b; Appendix N Schedule L-1). In many cases, tree retention targets for riparian zones are estimated using simulation and field experiments for their efficacy in providing shade for temperature regulation and material input (discussed above). Still, the scientific basis for these targets from a silvicultural perspective is unclear. Dwire et al. (2010) discuss the potential effects of fuel reduction treatments within riparian areas on function (e.g., shade, in-stream LW recruitment, sediment dynamics, nutrient cycling), vegetation structure, terrestrial habitat, and soil chemistry. The authors list management implications for riparian zone fuel reduction treatments in their review. Most of the treatment suggestions Dwire et al. (2010) provide focus on the inherent effects on function (e.g., shade, LW, etc.), but one relevant to riparian vegetation and structure states, "Objectives for fuel 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 conditions of uplands and riparian areas."

There is a paucity of riparian zone silvicultural studies across North America. Clear cutting to the stream bank was common practice in the Pacific Northwest through the late 1970s (Richardson et al. 2012), and 40-50-year-old stands are just reaching the age where the effects of thinning can be assessed. We found no studies that have theorized or tested preferred silvicultural practices and treatments specific to forested riparian areas on stand development in the Intermountain West. The few riparian silvicultural recommendations we found focused on the eastern U.S. and central Canada. In both regions, thinning experiments have shown evidence of changes in the composition of the regeneration of early and late successional species in the groundcover and understory layer in the years immediately following thinning (Palik et al., 2012; Zenner et al., 2013; Kastendick, 2014; Mallik et al., 2014) but we found an absence of long-term thinning studies in riparian areas. Before-after monitoring of preferred species compositions and undesirable species invasion would provide further knowledge of how thinning prescriptions affect the development of groundcover.

### *Disturbance*

The general goal of the Forest Practices Rules is to meet the goals of the Forest and Fish Report which are: 1) to provide compliance with the Endangered Species Act, 2) restore and maintain riparian habitat, 3) meet requirements for the Clean Water Act, and 4) keep the timber industry economically viable (FFR 1999). This requires implementing prescriptions that balance timber production and land use with "natural" forest function. In the West, in addition to forest practices wildfire is the predominant disturbance focus for land management. Land management philosophies throughout the West (eastern Washington included) are shifting from focusing exclusively on fire suppression and maximizing timber production to more “intentional management” (proactive thinning) that seeks to emulate historical disturbance regimes that drive forest ecosystem development and succession (Schimel & Corley 2021). Other disturbances (e.g., windthrow, ice damage, disease, invasive species, insect pests etc.) also influence forest structure and composition but this review will focus on fire as the most influential natural disturbance affecting forest structure and species composition in eastern Washington's semi-arid and arid landscapes.

Studies of reconstructed historical fire regimes in the West have shown that fire suppression and early twentieth-century harvest techniques have led to a change in forest structure and species composition that has influenced the susceptibility and severity of fire. For example, Merschel et al. (2014) showed that fire suppression and timber management in eastern Oregon reduced the density of large trees by half and doubled the density of smaller trees in many forest types compared to pre-European settlement. They found that the forest type with the greatest departure from the historical structure was in warm-moist environments (mixed conifer) with higher numbers of small diameter stems. In the northern Sierra Nevada, Van de Water and North (2011) found that riparian areas specifically are more fire-prone, based on current structure and fuel loads, than reconstructed historical conditions. Fuel reduction management in riparian zones is a relatively new practice in the West, and the effects on riparian health, development, and function remain unclear (Stone et al., 2010; Dwire et al., 2010). Messier et al. (2012) showed fire is an essential process in the riparian zones to maintain the variability of forest vegetation structure and composition. Malison and Baxter (2010) showed that fire provides pulses of in-stream chemical and structural variation that stimulates aquatic productivity and flux of prey to terrestrial habitats, driving local increases in riparian consumers. Flitcroft et al. (2016) modeled the potential effects of wildfire on Chinook salmon habitat in the Wenatchee River subbasin in central Washington. The authors modeled the effects of wildfire on fine sediment input, wood input, and stream temperatures to assess the quality of pre- and postfire habitat potential for three life stages of Chinook salmon. The results showed the potential of wildfire to increase the quality of habitat for adults and juvenile life stages of the Chinook salmon while decreasing the quality of habitat for the egg and fry life stages. Their investigation also revealed there was a limited availability of high-quality juvenile life stage habitat pre-fire. These results suggest that fire suppression in these areas may limit quality Chinook habitat for some life stages. While thinning treatments within riparian zones may recover some function (reduced competition, reduced susceptibility to higher severity fires), desirable outcomes for other important and natural processes (e.g., bank stability, sediment filtration, shade, etc.) might not be achieved. Therefore, regular monitoring and analysis remain important and fundamental components in gaining a better understanding of the effects of fire management on riparian functions.

## Other Agencies

The following is a brief review of how other public agencies intermingled with, and adjacent to lands subject to the Washington State Forest Practices Rules address riparian classification and management. It is presented solely as background and context for how other management entities approach classification and management of riparian areas similar to those encountered in ETHEP. Agency mandates guiding riparian management differ among agencies on lands subject to the Washington State Forest Practices Rules. National forests are guided by aquatic conservation strategies incorporated in each Forest's Land Management Plan. In comparison, western states have rules and regulations for riparian timber harvest on non-federal land (state, private, tribal, etc.). Regulations vary because ecological factors, laws, and stakeholder interests can differ considerably. However, the rules generally aim to preserve and restore viable salmonid habitats and maintain water quality in the western states.

### *National Forests*

In eastern Washington the USFS classifies and delineates riparian areas based on valley width and gradient separated into four channel types; and vegetation divided into several common dominant riparian zone covertypes. The fluvial surfaces that define channel types are described by upland, slope toe, upper terrace, fen, floodplain, streambank, and bar. The different fluvial surfaces and their width can affect the processes that drive riparian function. Covertype classifications are separated into the seven most common conifer species, a mixed conifer group that contains less commonly occurring conifer species (mainly subalpine larch, lodgepole pine, and Douglas-fir, which is more common in non-federal forest lands and lower elevation plots), aspen and willows, and a mixed deciduous (mainly alder, birch, maple, and oak). The dominant deciduous covertypes are not recognized as important timber species but are considered beneficial for riparian health. The dominant conifer covertypes are described by their elevational ranges, life history, and historical disturbance regimes (fire) that help inform their management options. Management options for regeneration, timber yield, function, and ecosystem services are described in Kovalchick & Clausnitzer (2004) for each delineated riparian covertype on federal land. The approach of the federal delineation system of riparian areas of eastern Washington is like other federal forest land classification systems that focus primarily on dominant covertype but also incorporate geomorphological information. This approach combines attributes from landscape-level (e.g., elevation, valley morphology) and ecosystem-level classification (e.g., vegetation characteristics, fluvial surfaces, soils) to determine the size of the riparian area. In a synthesis and evaluation of forestland classification methods, Pregitzer et al. (2001) note that while these methods, in conjunction with one another, are effective at understanding current and future habitat conditions, they potentially focus too much on climax communities (or other preferred successional levels) and leave out important information about the structure, understory composition, other potential covertypes, and variation in successional status. The methods used for delineation of federal riparian areas are discussed in more detail in the methods section.

The application of this riparian classification system varies among the National Forests intermingled with lands subject to the Washington State Forest Practices Rules and are prescribed in each Forest's Land Management Plan. Generally, each Forest is tasked with maintaining forest productivity and viable habitat for a variety of important and protected aquatic and terrestrial species. For example, the Okanogan-Wenatchee National Forest Management Plan imposes riparian buffer regulations described in the Northwest Forest Plan Aquatic Conservation Strategy. Under this plan, the variations for buffer width regulations and prescriptions are assessed at a watershed level and are based on preserving and restoring key ecological processes (e.g., habitat, natural disturbance regimes, etc.). Expected riparian management widths for perennial fish-bearing streams are a minimum of 150 feet for first, second and third order streams with incremental increases of up to 240 feet for sixth order and greater streams (NWFP-FSEIS, 1994). Buffer widths and prescriptions for the Colville National Forest are described in the 2019 Colville National Forest Plan Programmatic Environmental Impact Statement best management practices (BMPs) for riparian management areas. Under these guidelines, no standard, measurable buffer width is imposed on riparian zones. However, the target prescriptions are designed to preserve desirable functions and characteristics of the riparian areas (LW, vegetation coverage, habitat) that extend various distances from the stream (e.g., maintain 80% cover on fish-bearing streams). The widest buffer prescription requires a 250-foot distance from bankfull width for soil protection, maintaining < 10% soil exposure (FEIS, 2019). Under this plan, riparian habitat conservation areas (i.e., riparian management areas) of fish-bearing streams have a minimum buffer requirement of 300 feet slope distance from the outer edge of the 100-year floodplain. This buffer width regulation applies to all Colville National Forest fish-bearing streams regardless of the selected plan alternative.

### *Tribal Lands*

Tribal nations of eastern Washington manage forested riparian areas under a different plan than federal and state governments. The two largest governing entities of tribal lands in eastern Washington are the Yakama Nation and the Confederated Tribes of the Colville Reservation. Current riparian management practices for the Yakama reservation are described in the Forest Management Plan: Yakama Reservation developed in 2005. The most current riparian management practices for the Colville reservation are found in the 2015 Forest Management Plan: Colville Indian Reservation. Both forest management plans prescribe riparian buffer widths and management practices on a site-by-site basis.

The Yakama Nation manages 10,403 acres of forested riparian areas. Under this management plan, there are no fixed buffer width prescriptions for riparian areas except for a 20-foot buffer adjacent to all streams where machinery use is prohibited. Beyond the machinery-exclusion zone, the guidelines for riparian management are more nuanced and use an “adaptive modified approach to protection.” Thus, specific buffer width and resulting prescriptions are dependent on site context. Buffer delineation varies for each site based on flood-prone area, area of active channel migration, the extent of riparian and potential riparian vegetation, soil type, adjacent sideslope sensitivity, and extent of potential LW contributing vegetation. Special circumstances such as the presence of important or protected riparian-dependent species (e.g., American beaver) presence, or the potential of old growth stands may further extend the buffer area.

The Confederated Tribes of the Colville Reservation manages more than 28,000 acres of forested riparian areas defined by the Colville Forest Practices Act. Under this management plan, riparian areas are removed or deemed ineligible for commercial harvest. There is no standard buffer width or riparian management area delineation method described in this plan. Instead, the protection of riparian areas is noted in each best management practice section. For example, under the road maintenance and construction BMPs, any “Streambanks and riparian areas exposed (non-vegetated) by management activities, construction or natural impacts are to be re-vegetated immediately.” For silvicultural prescriptions, the management plan requires a variety of systems that vary from site to site based on local needs and objectives. The only treatments described in this plan that use thresholds for prescription advisement are for leave tree and coarse woody debris retention. For these prescriptions, riparian areas are divided into “dry’ and “moist” forest types.

### *Oregon*

Eastern Oregon contains many features and habitats similar to those in eastern Washington, especially along the east Cascade Region and the Blue Mountains. The most current regulations for fish-bearing streams for non-federal lands in Oregon are presented in the Oregon Department of Forestry Rules and Forest Practices Act Chapter 629. These rules were created in response to the 2012 Oregon Board of Forestry decision that previous regulations of riparian buffers needed to be revised in protecting desirable fish and aquatic species habitats. Oregon rules do not use a habitat classification system to assign buffer widths and regulations. Instead, the riparian areas are classified by stream type (e.g., fish-bearing, non-fish-bearing) and further subdivided by stream size.

Stream temperature was the primary factor in maintaining these habitats; thus, shade models were used to develop harvest regulations and classification of riparian areas. Groom et al. (2018) derived one of the models used in determining acceptable harvest levels based on their effects on shade reduction and, consequently, stream temperature increases. While the results of this model suggested the most effective method of reducing stream warming required a 27.4 m (90 ft) no-cut-slope-distance buffer width, the regulations implemented have varied, and riparian management area widths are dependent on the size of the stream.

Fish-bearing streams (Type F) have a general, state-wide buffer width prescription regardless of region. Riparian areas along fish-bearing streams are classified by stream size. Streams are divided into three classes based on average annual flow: small = 2 cubic feet per second or less, medium = greater than 2 and less than 10 cubic feet per second, and large = greater than 10 cubic feet per second. The designated riparian management area (RMA) widths are 50 ft, 70 ft, and 100 ft as measured from the bank full width (BFW) for the small, medium, and large stream flow classes, respectively. All RMAs contain a no-cut policy for all trees within 20 feet of the BFW, any trees leaning over the channel, and all understory vegetation within 10 ft of the BFW. In addition, all downed wood and snags that are not safety or fire hazards must be retained, and any snags felled to reduce risks must be retained where they are felled.

### *Idaho*

Idaho has no standard no-cut-buffer width for streams of any class or order, but landowners are encouraged to leave trees immediately adjacent to streams. The riparian area timber harvest regulations have recently been updated as of March 2022. The change came in response to a before-after control-impact (BACI) experimental analysis of the “old shade rule” implemented in 2014 (Link et al., 2019). Results of this study suggested that the harvest targets of the old shade rule resulted in a shade reduction that was 50% less than expected and thus was an over-regulation of landowners. The Idaho Department of Lands cited this paper as a need to revise the Class I tree retention rule, and the new “Shade Rule” was approved by the Idaho Legislature.

The current shade rule uses a weighted tree count (WTC) based on tree diameters (i.e., larger trees are higher weighted) with varying weights required by region and covertype. The riparian management zone for all fish-bearing (Class I) streams is 75 ft wide as measured from the high-water mark, and targets are defined for 100 ft reach increments. Idaho is divided into three regions from north to south, and the target weights become lower moving south. The lowest weights are for “drier forest” forests dominated by Douglas-fir and ponderosa pine. Regulation of non-tree vegetation and streamside rocks is not explicitly regulated. It is only required to be left in areas where they provide shade over the stream and stabilize the soil. Any LW is to be left in RMZ if longer than the stream width or 20 ft; or sufficiently buried to maintain position during flooding and high-flow events.

*California*

Current regulations and prescriptions in California were taken from the California Forest Practice Rules 2022. California has the most variation in riparian management prescriptions and the widest no-cut buffer area relative to Washington, Oregon, and Idaho. The riparian buffer’s width depends on the slope, proximity to anadromous migration/spawning areas, and potential for flooding. Regulation of timber harvest in management areas adjacent to fish-bearing streams (Class 1) is prescribed by zones (core, inner, outer). The core zone is a 30 ft wide no-cut buffer where all trees are retained. The width and prescriptions of the inner and outer zones vary depending on whether they are located within the coastal anadromous region (western California) and if valley morphology allows for flood-prone areas or is more confined.

Class 1 streams with flood-prone areas or channel migration have a minimum inner zone of 70 ft and a maximum of 120 ft, depending on the size of the flood-prone area. Within the inner zone, canopy cover should not be reduced below 80% if the stream is in the coastal anadromous habitat and 70 % for all other watersheds. A minimum of 13 of the largest trees per acre must also be retained in the inner zone. The outer zone extends another 50 ft from the inner zone, and the canopy cover minimum is 50 % post-harvest. There is no regulation for large tree retention in this zone, but it requires retaining wind-firm trees.

In confined channels, the inner zone is 70 ft in the anadromy zone and 40 ft in all other watersheds. The canopy cover minimum is 70 % for both habitats, and the largest tree retentions are 7 and 13 per acre for the anadromy and non-anadromy watersheds, respectively. The outer zone is 50 ft in the anadromy zone and 30 ft in other watersheds; the canopy cover minimum is 50% for both habitats.

The governing entities described above define, delineate, and manage riparian areas adjacent to fish-bearing streams differently. For example, buffer widths and their prescription targets can vary based on stream size, valley morphology, fluvial process, landscape position, and vegetation structure and composition, or a combination of these factors. This variation in delineation and regulation describes the context-dependent range of priorities for desirable functions, physiography, and vegetation of forested riparian areas in these western states. Below we discuss several potential methods for developing, refining, and validating riparian management systems that delineate riparian areas based on these variations in physiography and vegetation as relevant to lands subject to the Washington State Forest Practices Rules.

# Project Description

*Problem Statement*

The current THT system of three fixed elevation zones is generally too coarse to accurately capture the diversity and complex distribution of eastside riparian forest composition and structural characteristics (Daubenmire et al., 1980; Franklin & Dyrness 1973). Although elevation has a major influence on local climate and consequently on vegetation patterns, forest site potential (productivity) can vary by localized topographic, climatic, and edaphic (soil) conditions that do not strictly follow elevation zones (Cooper et al. 1991). Thus, there can be differences in forest composition and structure at similar elevations – or expected similarities in forest composition and structure at different elevations – depending on local microclimate, topographic, and other environmental conditions. These differences may be especially pronounced for riparian forests which are strongly influenced by fine-scale changes in hydrology (Naiman et al. 2005). Therefore, an analytical framework is needed for classifying the diversity of eastside riparian forest composition and structural characteristics. For the purpose of this study, a framework is generally defined as a classification system that can be used to inform and guide management prescriptions that support the goals and objectives of the FPHCP. Hereafter, the framework(s) we propose will be a classification system and will be referred to as such. A classification system developed from important ecological factors could be used in the future to develop site-appropriate riparian harvest prescriptions to better meet the stated goals of the FPHCP (2005) for managing eastside riparian forests.

*Purpose Statement*

The purpose of this project is to develop a framework (classification system) for applying riparian harvest rules along Type S and Type F streams in eastern Washington based on the functional objectives and performance targets of the Forest Practices Habitat Conservation Plan (FPHCP) (Schedule L-1, Appendix N).

*Study Area*

ETHEP will be conducted on lands subject to the Washington State Forest Practices Rules in Eastern Washington, defined as the portion of the state prescribed in WAC 222-16-010, hereafter referred to as “eastern Washington” (Figure 1). Eastern Washington is a landscape of sharp contrasts between the steep mountainous topography of the Cascade Range, the gentle terrain of the Columbia Basin, the Selkirk Mountains in the northeast, and the Blue Mountains in the southeast. Portions of five ecoregions occur within eastern Washington, including the East Cascades, Okanogan, Canadian Rocky Mountains, Columbia Plateau, and Blue Mountains ecoregions (WADNR 2007). These ecoregions are used to partition the landscape based on similarities in physical characteristics and the ecosystems they support. Each ecoregion has a generally distinctive composition and pattern of plant and animal species distributions. The following ecoregion descriptions have been adapted from the *State of Washington Natural Heritage Plan 2007* (WADNR 2007).

The **East Cascades Ecoregion** falls east of the Cascade crest from near Lake Chelan south to the Oregon-California border. The climate ranges from cold and wet with over 300 cm (120 inches) of precipitation per year along the Cascade crest to hot and dry with less than 50 cm (20 inches) of precipitation per year along the foothills. Most precipitation falls during November through April, with snowpacks accumulating at higher elevations. The majority of the ecoregion occurs between 610 and 2135 m (2000 and 7000 feet) in elevation. A diversity of coniferous forests dominates this ecoregion, with grand fir (*Abies grandis*)–Douglas-fir (*Pseudotsuga menziesii*)–ponderosa pine (*Pinus ponderosa*) forests being common. Subalpine fir (*Abies lasiocarpa*)–mountain hemlock (*Tsuga mertensiana*)–Engelmann spruce (*Picea engelmannii*) forests are found at the higher elevations, and Douglas-fir–western hemlock (*Tsuga heterophylla*)–Pacific silver fir (*Abies amabilis*) forests are locally abundant near low divides of the Cascades. Lodgepole pine (*Pinus contorta*), and western larch (*Larix occidentalis*) are common components of these forests.

The **Okanogan Ecoregion** extends east to the Selkirk Mountains from the Cascade crest in the North Cascades. The Okanogan receives cold, dense arctic air in winter and hot, dry air from the Columbia Basin during the summer. Annual precipitation ranges from less than 30 cm (12 inches) in the Okanogan Valley to between 127 and 229 cm (50 to 90 inches) in the Cascades, with most of the ecoregion receiving 36 to 61 cm (14 to 24 inches). Elevation ranges from about 230 to 2865 m (750 to 9400 feet). Coniferous forests dominate the mountain ridges and low hills, including Douglas-fir–ponderosa pine forests at lower elevations, and subalpine fir–Engelmann spruce occurring at higher elevations. Moister forests are dominated by Douglas-fir, with western larch, western white pine (*Pinus monticola*), or quaking aspen (*Populus tremuloides*) as common components. The **Okanogan Highlands province** within the eastern portion of the Okanogan Ecoregion from the eastern foothills of the Okanogan Valley to the border of the Canadian Rockies ecoregion, is characterized by dominant stands of lodgepole pine (Pinus contorta) due to its unique rolling topography and drier climate (Van Pelt 2008).

The **Canadian Rockies Ecoregion** is located in the northeastern corner of Washington. Annual precipitation ranges from 46 to 203 cm (18 to 80 inches), with most of the ecoregion receiving between 61 and 86 cm (24 and 34 inches). Substantial snowpack accumulates at mid and upper elevations. Elevation ranges from 396 m (1300 feet) at the Columbia River to over 2130 m (7000 feet) in the Salmo-Priest Wilderness Area. This ecoregion is dominated by coniferous forests, including Douglas-fir–ponderosa pine forests at low elevations, grand fir–western hemlock–western redcedar (*Thuja plicata*) forests at mid-montane elevations, and subalpine fir–Engelmann spruce forests at higher elevations.

The **Blue Mountains Ecoregion** extends from adjacent Idaho and Oregon into the southeast corner of Washington. Annual precipitation ranges from less than 25 cm (10 inches) in the Grande Ronde River canyon to over 125 cm (50 inches) in the Wenaha-Tucannon Wilderness Area, with most of the ecoregion receiving between 35 and 61 cm (14 and 24 inches). Much of the precipitation occurs as snow, although spring and fall rains are common. The elevation within this ecoregion ranges from 230 m (750 feet) along the Snake River to over 1830 m (6000 feet). This ecoregion is dominated by coniferous forests, including Douglas-fir–ponderosa pine forests at low and middle elevations, and subalpine fir–Engelmann spruce occurring at higher elevations. In addition, western larch, lodgepole pine, and western white pine occur within mesic forests.

The **Columbia Plateau Ecoregion** includes the area in eastern Washington bounded by the Cascade, Okanogan, Blue Mountains, and Rocky Mountains. This is the hottest and driest ecoregion in Washington, falling within the rain shadow east of the Cascades. Annual precipitation ranges from 15 cm (6 inches) along the Columbia River's Hanford Reach to 64 cm (25 inches) in the Palouse Hills, with most of the ecoregion receiving between 20 and 36 cm (8 and 14 inches). Elevations range from 50 m (160 feet) along the Columbia River to nearly 1220 m (4000 feet) on isolated hills. The Columbia Plateau is dominated by shrub-steppe vegetation. Douglas-fir–ponderosa pine forests occur on moister sites near the foothills of surrounding mountains.

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The target population for this study includes riparian forest stands along fish-bearing streams (Type S and Type F) in eastern Washington that are likely to be harvested under the FPHCP ( WAC-222-30-022(1)) (Figure 1). Approximately 41% of the target population occurs in the Okanogan ecoregion, 29% occurs in the East Cascades ecoregion, 17% occurs in the Canadian Rocky Mountains ecoregion, 11% occurs within the Columbia Plateau ecoregion, and 2% occurs within the Blue Mountains ecoregion.

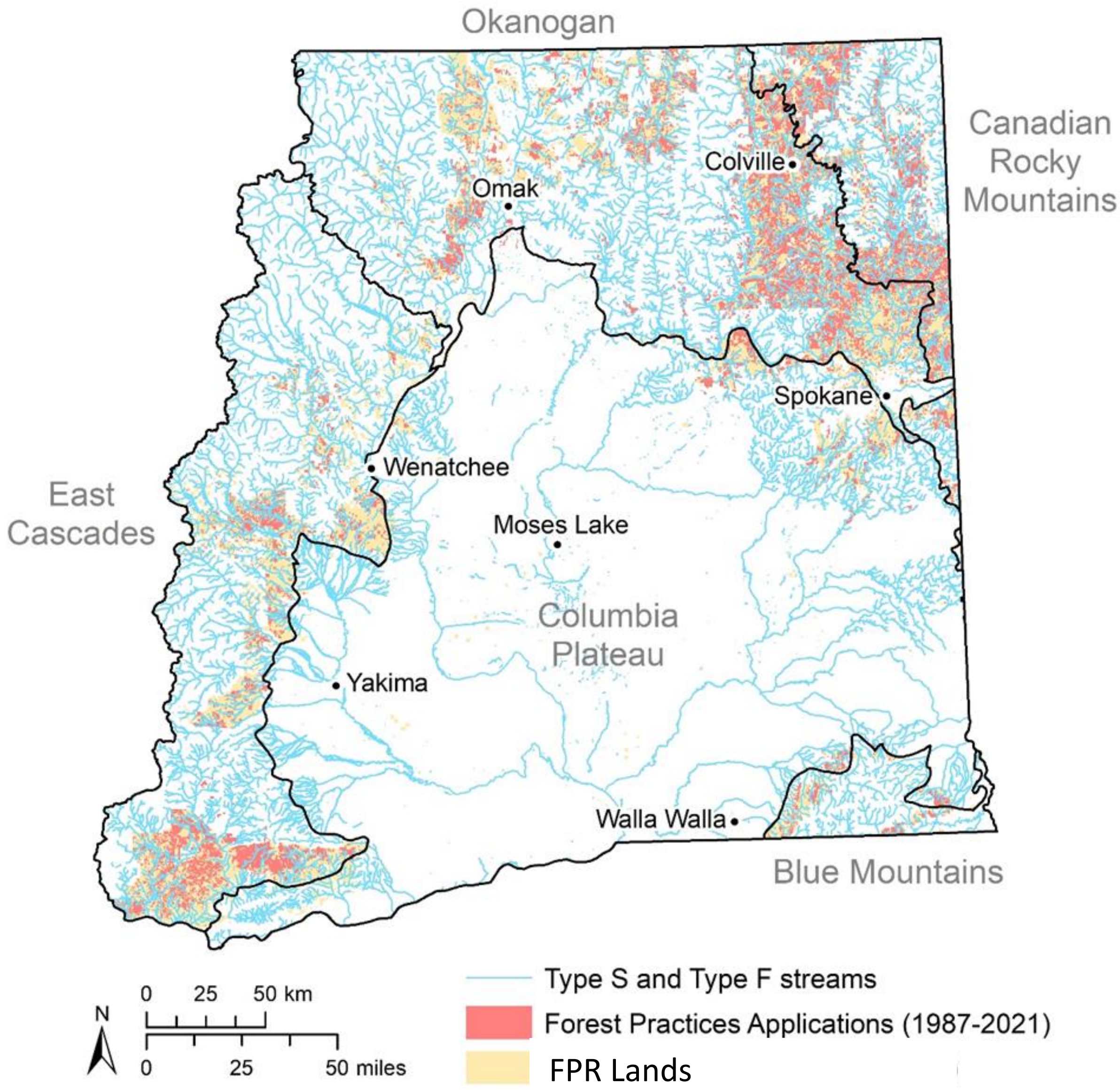

Figure 1. Eastern Washington (east of the Cascade crest) includes portions of the East Cascades, Okanogan, Canadian Rocky Mountains, Columbia Plateau, and Blue Mountains ecoregions (WADNR 2007). The approximate target population (lands subject to the Washington State Forest Practices Rules defined by the FPHCP; FPR lands) includes riparian forest stands along fish-bearing streams (Type S and Type F) in eastern Washington that are likely to be harvested under WAC-222-30-022(1)

## Methods

ETHEP seeks to develop a classification system based on timber management objectives (FPHCP objectives). Because the goal of the classification system is to guide efficient implementation of timber management, we seek a system that divides the subject area into a limited number of classifications that provide for effective implementation of forest practice rules while still satisfying FPHCP objectives. In Phase 1 of this design, we will develop a preliminary classification system from existing geospatial data sets. In Phase 2, we will validate, fill in data gaps, and revise the classification system developed in Phase 1. Both Phases will explore the use of 3 different classification methods (Habitat Typing, Multi-factor Classification, Forest Productivity modeling), described below.

### *Habitat Typing*

These methods for habitat typing as a classification system were developed by Layser (1974), applied to several areas of the western U.S. (Pfister 1976), and are described in detail by Pfister and Arno (1980). Kovalchik and Clausnitzer (2004) used a habitat typing system based on climax community vegetation associations for wetland, riparian, and aquatic sites in national forest lands of eastern Washington. Each unit in this classification system is based on series, plant association, and community type. This system has also been used to delineate riparian zones of Montana in Classification and Management of Montana's Riparian and Wetland Sites (Hansen, 1995) and in the Malheur, Umatilla, and Wallowa-Whitman National Forests of Oregon (Crowe & Clausnitzer, 1997).

Generally, this system is a "top-down" approach to classification that begins with field data that estimates dominant and codominant canopy coverage classes of all vegetation. These assemblages are grouped by community similarities as "types", and patterns recognized in the a priori assessment are used to estimate potential delineations and indicator species. Vegetation community groupings are estimated using association tables that provide a more objective technique for delineating vegetation groups by similar floristic characteristics. These initial approximations are then revised through an iterative process of ordination and grouping along environmental gradients (physiography, moistures, and soil characteristics) until a preliminary classification is developed. From Hall (1973), and reproduced in Kovalchik and Clausnitzer (2004), for plant assemblages to be classified as a series or association (or community type), four criteria must be met: the series 1) differs from other plant associations in opportunities and limitations to land management, 2) can be recognized on the ground in any stage of disturbance 3) has limited variation in species composition, and 4) has limited variability in productivity. The classification is then further validated (or revised) through field testing until a final classification is developed.

### *Multi-factor Classification*

Another commonly used classification system is the multi-factor classification system originally developed in Baden-Württemberg in the 1940s (Schlenker 1964) and first applied, modified, and validated for use in the United States by Barnes et al. (1982) in northern Michigan. Since then, it has been used to delineate and classify multiple ecosystems of the midwestern, eastern, and southwestern United States (Pregitzer & Barnes, 1984; Spies and Barnes, 1985; Hix, 1988; Goebel et al., 2001; Abella and Covington 2006). The approach of the multi-factor classification system is similar to the habitat typing system in that it is an iterative process that begins with a grouping of classification units from a priori assessment of field data. However, this approach puts more weight on physiography and soil characteristics than on vegetation during the ordination and validation process, as they are more stable than vegetation. Thus, it is considered well-suited for areas that have been recently disturbed or have an unknown disturbance history (Barnes et al., 1982).

Classification units are grouped by similarities in 1) physiography, soil, and vegetation, 2) growth and yield (e.g., site index), 3) silvicultural potential (e.g., preferred species), and 4) susceptibility to damaging agents. Initial a priori classifications of units are made when different combinations of physiography-soil-vegetation (PSV) are identified. A unique PSV combination determined from spatial data sets is considered valid as a tentative classification if 1) they repeat throughout the landscape and are of sufficient size (e.g., > 1 ha), and 2) the hypothesized relationship of the PSV combination is valid in terms of ecological theory regarding plant-environment interactions and the physical ecosystem processes of soil and physiography (Spies & Barnes 1985). During the preliminary classification development process, physiography is given the most weight, followed by soil and then vegetation, as physiography is the most stable and vegetation least stable. For example, when vegetation is different, but physiography and soil are similar, units will not be separated (i.e., vegetation is considered dynamic within classification units). Vegetation data is used in grouping analysis at multiple strata (Overstory, understory, groundcover) to incorporate structural differences.

### *Forest Productivity Modeling*

The third approach to forest delineation and classification involves quantifying forest productivity. In general terms, forest productivity can be modeled as a function of site growth factors (e.g., temperature, moisture, soil) to predict either the rate of growth (site index) or the carrying capacity (maximum stand density) of desirable tree species at a specific location. Maximum stand density models can be modeled with site index as a covariate to estimate site quality, predict the rate of development, and the expected yield of wood volume for a particular species, creating maximum stand density index models (MSDI) (Long & Shaw, 2005; Weiskittel et al., 2009; Ducey et al., 2017). Kimsey et al. (2019) identified the effects of specific abiotic factors (e.g., climate, topography, edaphic) on the size-density relationships for ponderosa pine, Douglas-fir, and grand fir across their inland range in Washington, Oregon, Idaho, and Montana. These MSDI models developed are thus site-sensitive and can be adjusted for different levels of species mixing and different future climate scenarios (i.e., climate change). Currently available models for species site index, maximum density, and thus MSDI in the Northwest, however, have all been developed for upland (non-riparian) forests. To calibrate a MSDI with confidence for the riparian areas of eastern Washington, an investigation of site index and maximum stand density for multiple representative riparian sites will be necessary.

# Phased Approach

ETHEP will be accomplished in 2 Phases. Phase 1 will contain 3 steps. Step 1 of Phase 1 is an exploratory analysis that will involve the organization, appraisal, and possible combination of publicly available data sets for site, vegetation, and landscape features characterizing the study area. Each data set will be evaluated using criteria outlined below that rank their ability to characterize and differentiate riparian stands, their ability to inform the classification system development, and their utility in simulation modeling. The factors[1] important for the development of the classification system that link the system to the FPHCP objectives (riparian forest function, health, and disturbance) were identified from the results of relevant experimental and simulation studies discussed in the literature review section. The relationship between each factor and one or more of the FPHCP resource objectives is outlined in Table 1 below. Specific methods and techniques for evaluating and potentially combining data sets will be developed once all data sets are cataloged and details of spatial scale, coverage, source date, type, etc., are recorded and organized.

Step 2 of Phase 1 will involve the development of one or more preliminary classification systems using one or more of the three methods described above (habitat typing, multi-factor analysis, and forest productivity modeling).: All methods will be used to seek reliable and meaningful discrimination of riparian classification units based on physiographic, environmental, and vegetation factors. Again, we will use factors available in the data sets that relate to one or more of the FPHCP objectives outlined in Table 1. In short, we seek to identify riparian classification units that represent meaningful differences in riparian function, forest health, and disturbance. The classification system development process in this step will also reveal any inconsistencies or gaps in the data and data needed for field data collection, classification accuracy assessment, and further refinement in Phase 2.

For step 3 of Phase1 we will use the Forest Vegetation Simulator (FVS) to estimate the trajectories of stand density, tree size, standing volume, insect and disease susceptibility, and wildfire risks under no-management scenarios and under disturbance scenarios reflecting historic anthropogenic and natural patterns. Output from the simulation modeling will be used to combine or separate classification units determined by the preliminary classification system development where outcomes among units are similar or where outcomes within units are highly variable. For instance, if trajectories for several initial classification units appear to converge, then combining the initial classifications into one may be considered. Conversely, simulations that show divergent pathways provide evidence confirming needs for separate classification units.

At the end of this Step, the resulting classification system will be presented to SAGE/CMER for their expert evaluation, and their suggestions for coarsening and refinement will be incorporated. This step will also reveal inconsistencies or gaps in the data that need to be addressed in Phase 2.

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[1] Factor in the context of this project is defined as the riparian area attributes that have been identified as influencing riparian function, stand health, and disturbance. A list of these factors is presented in Table 1.

From the information learned during Phase 1, steps 1-3, we will develop methods and protocols for field data collection to validate the classification system, and fill-in any data gaps.

Phase 2 will involve targeted field surveys to 1) remedy any gaps or inconsistencies in the publicly available data sets used in Phase 1 and 2) further test the ability of the classification system to characterize riparian areas supportive of FPHCP objectives. Step 1 involves field data collection and analysis of remote sensing data. The data collected during this Phase will be used to validate, assess, and refine the proposed classification system from Phase 1 even further and with more confidence. A general description of the types of data and methods expected for collection are described and presented in the *Field Data Collection* and *LiDAR-derived Data* section of Phase 2. More precise methods for field data collection will have been developed at the conclusion of Phase 1 after specific data needs are determined.

Step 2 of Phase 2 will involve an accuracy assessment and simulation modeling to evaluate and refine the classification system using the data collected in Step 1. Potential options for these procedures are described and reviewed in the *Accuracy Assessment* and *Refinement* sections of Phase 2. Similar to Phase 1, Phase 2 will conclude with a report to SAGE/CMER for input on the practical use of each classification system. Following feedback from SAGE/CMER, the classification system may be further refined to address any concerns. Another iteration of accuracy assessment and simulation modeling may be undertaken to refine the system further if needed. Classification system development will be an iterative process informed by publicly available data and field-based data, validation via classification accuracy assessments and simulation modeling, and evaluation by expert groups for utility and practical applicability.

### *Phase 1*

### *Step 1: Evaluation of Available Datasets*

Publicly available and relevant datasets will be evaluated using criteria outlined below that discriminate their ability to characterize and differentiate riparian stands in eastern Washington. Where these standards are not met, data sets will be eliminated from further analysis. The analysis will also examine the relationships among the datasets, including where there is agreement and disagreement in estimated values for variables of interest.

Publicly available geospatial datasets that will be evaluated include:

- Landscape Ecology, Modeling, Mapping, and Analysis (LEMMA) dataset produced by the USDA Forest Service, Pacific Northwest Research Station, and the Department of Forest Ecosystems and Society at Oregon State University (e.g., Ohmann and Spies 1998, Ohmann et al. 2011). The gradient nearest neighbor (GNN) data consist of quantitative maps of forest vegetation based on imputations of numerous attributes (e.g., species, density, basal area, canopy cover, height, diameter) collected by Forest Inventory and Analysis data. GNN imputation is based on a multivariate analysis that integrates FIA data with 30 m Landsat imagery and other geospatial data, such as climate and topography.

- Modeled Potential Vegetation Zones of Washington and Oregon and Modeled Plant Association Groups of Washington and Oregon produced by the USDA Forest Service and hosted by Ecoshare, the Interagency Clearinghouse for Ecological Information.
- Ecological Systems of Washington produced by NatureServe and the Washington Natural Heritage Program (Rocchio and Crawford 2015).
- Maximum Stand Density Index models developed by the University of Idaho Intermountain Forestry Cooperative (Kimsey et al. 2019).
- Public data for the 20-year Forest Health Strategic Plan: Eastern Washington (Washington Department of Natural Resources); https://bit.ly/ForestHealthData.
- Climate data and Predictions (USDA Forest Service).
- Maps of Specific Forest Plant Species and Climate Profile Predictions (USDA Forest Service).
- Climate FVS Climate FVS is a stand dynamics model generally used to support forest planning, project analysis, and preparation of silvicultural prescriptions.
- Individual Tree Species Parameter Maps (USDA Forest Service). The Individual Tree Species Parameter Maps (ITSP) were developed to support the National Insect and Disease Risk Map (NIDRM). Basal area and stand density index are mapped for each individual tree species. The parameter products are based on 30-meter Landsat satellite data, climate, terrain, and soil predictor layers and ground samples from the USFS Forest Inventory and Analysis plot data.
- Forest Biomass geospatial dataset (USDA Forest Service). This product was created by modeling forest biomass collected on USFS Forest Inventory and Analysis sample plots as functions of more than sixty geospatially continuous predictor layers. Among the predictor layers used were digital elevation models (DEM) and DEM derivatives; Moderate Resolution Spectroradiometer (MODIS) multi-date composites, vegetation indices and vegetation continuous fields; class summaries from the 1992 National Land Cover Dataset (NLCD); various ecologic zones; and summarized PRISM climate data.
- Ecological Classification of Native Wetland and Riparian Vegetation of Washington. (Rocchio and Crawford, Washington Natural Heritage Program, *in progress*).
- SPTH/SitePotentialTreeHeightPublic (MapServer) SPTH/SitePotentialTreeHeightPublic (MapServer) (wa.gov)
- TreeMap, a tree-level model of conterminous US forests circa 2014 produced by imputation of FIA plot data TreeMap, a tree-level model of conterminous US forests circa 2014 produced by imputation of FIA plot data | Scientific Data (nature.com)

Several of these data sets were already identified in the Scoping Document. Others are included based on the project team's technical experts' subject area expertise. Others may be identified during study implementation.

Additional potential sources of existing field data include, but are not limited to:

- Eastern Washington Riparian Assessment Project (EWRAP) Phase 1 (Bonoff et al. 2008), produced by the Washington Department of Natural Resources – Cooperative Monitoring Evaluation and Research Committee (CMER). This dataset includes riparian stand data from 103 field sites in eastern Washington.

- PacFish/InFish Biological Opinion Monitoring Program (PIBO MP), produced by the USDA Forest Service. This program monitors stream and riparian conditions on US Forest Service, Bureau of Land Management, and National Park Service lands. Data are collected from watersheds throughout the Intermountain West, including eastern Washington.

- Forest Inventory and Analysis (FIA) Program managed by the USDA Forest Service. FIA monitors and reports on status and trends in the area, locations of different types of forests, ownership, numerous tree and stand metrics, timber harvest statistics, and agents of mortality for dead trees. The configurations of FIA field plots, data collection protocols, and analytical processes are consistent across the nation.

- LANDFIRE Landscape Fire and Resource Management Planning Tools, is a shared program between the wildland fire management programs of the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior, providing landscape scale geo-spatial products to support cross-boundary planning, management, and operations.

- NorWest Managed by the USDA Forest Service. The NorWesT webpage hosts stream temperature data and climate scenarios in a variety of user-friendly digital formats for streams and rivers across the western U.S. The temperature database was compiled from hundreds of biologists and hydrologists working for >100 resource agencies and contains >200,000,000 hourly temperature recordings at >20,000 unique stream sites.

We will also consider the classification of LiDAR data, in conjunction with one or more other available data sets. Options for LiDAR data collection are discussed in Phase 2.

A basic inventory of available data sets will be compiled, and cataloged by:

- Spatial extent
- Production date
- Update frequency (if applicable)
- Scale
- Resolution
- Error (if published in the metadata)
- Input variables/data sources
- Classification attributes

- Does the dataset differentiate between riparian and upland forest stands?

Methods for data set combination require intimate knowledge of these details (Stutter et al., 2021). For example, Stutter et al., (2021), in their review of methods for using spatial data to delineate river riparian functions and management discuss several methods for screening landscape data by combining available datasets with statistical and modeling approaches. The “key factors” they identify for consideration when combining spatial datasets for informing riparian management are 1) the spatial resolution and extent of the data available to define riparian zones, 2) the interpretation of the data with respect to the processes which it is used to represent. 3) the distinction between classes required from automated classification systems. For example, whether satellite image classification can give a fine enough distinction between vegetation classes as required for some ecosystem service appraisal, or whether the required outcomes can be achieved with coarser data categories.

Following the basic inventory, an assessment will be made of the data sets’ ability to discriminate riparian stands in eastern Washington, along with their associated riparian functions. The literature review identified a range of variables important to this discrimination (Table 1). An initial screening indicated concerns with the stand structure information and the spatial resolution of the data. These concerns will be followed up during study implementation and potential resolutions considered.

Several attributes will be considered in screening. A key attribute will be spatial coverage. If the coverage of the dataset includes coverage of Type S and Type F streams within lands subject to the Washington State Forest Practices Rules, then they will be retained for potential use. Any data set that specifically delineates riparian areas from adjacent uplands (e.g., LANDFIRE) will also be included. Next, the data will be organized and ranked on their potential use based on their resolution. In the event of insufficient coverage of certain characteristics, scaling up to coarser resolutions may be necessary.

Conversely, for utility in classification system development and simulation modeling, it may be necessary to change the resolution of datasets such as climate to match the resolution of finer-scale datasets such as vegetation. For example, climate data may have a resolution of 1 square kilometer, while other data layers such as vegetation and or slope may have a resolution of 30 square meters. To successfully combine these large differences in resolution the climate data would be “downscaled” to 30 square meter data resolution to increase compatibility. Last, the production date or date of the last update will be used to decide between datasets. The more recently updated datasets will be included when coverage and scale are deemed sufficient. Thus, datasets with the most complete coverage that specifically characterize the riparian area, provide relatively fine resolution, and have the most recent update/production date will be included for potential use in the classification system development. Any Type S and Type F streams within lands subject to the Washington State Forest Practices Rules that lack coverage or have a production date before the adoption of the THT prescriptions (2001) will be recorded as areas of priority for new data collection during Phase 2.

Step 1 of Phase 1 is an exploratory analysis of currently available data that may be used in the classification system development. As such, we will learn as we evaluate the data and, in learning, be able to identify important attributes that differentiate the utility of the data. For scoping implementation of this Study Design, an example evaluation may look something like as follows:

- Coverage
    - Data sets will be considered appropriate for inclusion if they cover any portion of lands subject to the Washington State Forest Practices Rules along the Type F and Type S rivers and streams. Datasets with characteristics that differentiate the riparian and upland areas will be noted.
    - Any areas of lands subject to the Washington State Forest Practices Rules along Type F and Type S rivers and streams lacking data coverage will be recorded for data collection during Phase 2.
- Scale/resolution
    - Expected resolution of datasets for factors deemed important for classification system development (Table. 1) based on publicly available datasets listed above.
        - If necessary, the resolution of some datasets may be reduced to datasets with finer resolution within the study area.
            - Landscape
                - Slope/Aspect (30 m resolution)
                - Elevation (10 m, 30 m resolution)
            - Vegetation
                - Dominant species coverage (30 m, 90 m, 240 m resolution)
                - Dominant groundcover (30 m, 90 m resolution)
            - Site
                - Soil (250 m, 1km resolution)
                - Climate (1 km resolution)
                - Fire history (30 m resolution, polygon datasets of various scales)
                - Harvest history (polygon datasets of various scales)
- Production date/ update frequency
    - Datasets with information recorded or updated after 2001 will be included for potential use.
    - Datasets with a production date or the most recent update before 2001 will be recorded as high priority for new data collection during Phase 2.

Table 1. Landscape (physical characteristics), vegetation, and site factors important for the development of a classification system. a Function (shade, LW, sediment, nutrient, litter), health, and disturbance factors that are theorized to have a relationship with selected landscape, vegetation, and site factors are marked with an "x." BFW = bank full width; FPA = flood-prone area; DTS = distance to stream; WD = woody debris, including snags and downed wood in the forested riparian area; damage agents include insects, disease, and windthrow.

| | *Riparian functions (FPHCP)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Factor** | **Shade** | **LWD** | **Sediment** | **Nutrient** | **Litter** | **Disturbance** | **Health** | **References** |
| ***Landscape*** | | | | | | | | |
| Slope | X | x | x | x | x | x | x | Bilby and Heffner 2016; Bywater-Reyes et al., 2018; Everett et al., 2003; Feld et al., 2018; Groom et al., 2018; Hook, 2003; Sobota et al. 2006; |
| Aspect | x | | | | | x | x | Dwire and Kauffman, 2003; Everett et al., 2003; |
| Elevation | | | | | | x | x | Cooper et al., 1991; Kovalcjik and Clausnitzer (2004); Franklin and Dyrness 1973 |
| Latitude | | | | | | x | x | Hemmingway and Kimsey, 2020; Wimme, 2022 |
| Area | x | X | x | x | x | | | Hough-Snee et al., 2016 |
| BFW | x | X | | | | x | | Feld et al., 2018; Ross et al., 2019; |
| FPA | | X | | | | | | Benda et al., 2003; Ross et al., 2019 |
| ***Vegetation*** | | | | | | | | |
| Species | x | x | | x | x | | x | Agee, 2003; Ross et al., 2019; Van de Water and North, 2011 |
| Basal Area | x | x | x | | x | x | x | Hough-Snee et al., 2016; Schuett-Hames and Stewart, 2019 |
| Density (stems/ha) | x | X | | | x | | x | Burton et al., 2016; Karwan et al. 2007; |
| Tree Height | x | X | | | x | | | |
| groundcover (%) | | | x | x | | x | x | Barnes, 1983; Feld et al., 2018; Hook et al., 2018 |
| DTS | | | | | | | | Ceder et al., 2018 |
| WD | | x | x | X | | x | x | Benda et al., 2003; Ross et al., 2019 |
| ***Site*** | | | | | | | | |
| soil | | | x | X | | x | | Barnes, 1983; Hix, 1988; Pfister, 1976; Pregitzer and Barnes, 1984; |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| site index | | x | | | | | | Weiskittel et al., 2009; Kimsey et al., 2019 |
| productivity | | x | | | | | | Hough-Snee et al., 2016; Liniger et al., 2017; Wohl et al., 2020; |
| climate | | | x | x | | x | x | Crandall et al., 2021; Hough-Snee et al., 2017; Liniger et al., 2017; Wohl 2020 |
| Fire | x | x | x | x | x | x | - | Churchill et al., 2022; Cooper et al., 2015; Crandall et al., 2021; Harris et al., 2018; Merschel et al., 2014 |
| Damage agents | | x | | | | | x | Ceder et al., 2018; Hermstrom 2001; Kovalchik and Clausnitzer 2004; Schuett-Hames and Stewart, 2019 |
| Harvest history | x | x | | | | | x | Anderson and Poage, 2014; Everett et al., 2003; Hix, 1988; kasten dick et al., 2014; Merschel et al., 2014; Pfister, 1976; Palik et al., 2014 |

*Step 2: Development of One or More Preliminary Classification System(s)*

The development of the classification system will begin with an approach that differentiates the landscape by one or more factors important for stand characteristics, stand development, riparian function, stand health, and disturbance regimes. One or more commonly used classification and delineation methods (described above) will be employed: habitat typing, multi-factor classification, and maximum stand density. The selection of the method will depend, in part, on the quality, availability, and accuracy of the data sets, as evaluated in Step 1. Classification systems from this analysis will be evaluated based on their ability to characterize and differentiate riparian stands, their health and fire resiliency, and their associated riparian functions (Step 3).

*Step 3: Simulation Modeling*

Regardless of which classification method is used, the separate classification units defined in Step 2 are expected to overestimate the number of units necessary to advise management prescriptions (Hix, 1988; Barnes et al., 1982; Spies and Barnes, 1985). Because the differences that separate these units, while theoretically and ecologically meaningful, may have little effect on riparian stand development and function over time, refining and coarsening of the classification system will use modeling of stand development, function (shade, LW), forest health, and disturbance under a no-management scenario and under disturbance scenarios reflecting historic anthropogenic and natural patterns. This first iteration of simulation modeling will use currently available datasets, such as the field data collected for the EWRAP study in 2008. Methods for the simulation modeling will follow a modified version of those described in Ceder et al. (2020; EMEP).

The EMEP study used field data collected by EWRAP from 103 sites across eastern Washington. Data was collected for large trees (> 3 inch diameter at breast height (DBH) and > 10 feet tall), included species, condition (live or dead), DBH, height, damage agent (e.g., insect or disease), crown class (e.g., dominant, co-dominant, intermediate, overtopped, open grown), crown ratio (percentage of crown fullness surrounding tree), distance to stream, and age (from increment cores). Smaller trees (< 3inch DBH) were tallied by species and categorized within 1-inch diameter classes. The EMEP study used Forest Vegetation Simulator (FVS) variants (Dixon et al., 2002): 1) Blue Mountains (Keyser & Dixon, 2008a) for sites in southeastern Washington; 2) East Cascades (Keyser & Dixon 2008b) for all sites along the eastern Cascade Mountains, northcentral and northeastern Washington; and Inland Empire (Keyser 2008) for all sites in northeast Washington. The Fire and Fuels Extension (FFE) (Rebain 2010) to simulate potential fire hazard rating was used to simulate potential fire hazard rating inputs. The dynamic computation (COMPUTE) functionality of FVS was used to calculate insect and disease rating inputs.

For this study, these data will be stratified by the newly developed classification units/types defined by the preliminary classification system (Phase 1, step 2). Simulation modeling will be conducted in a manner similar to EMEP.  Simulation will be conducted under a no-management scenario and under disturbance scenarios reflecting historic anthropogenic and natural patterns to obtain an estimate of stand successional trajectories (stand structure), disturbance susceptibility (insect, disease, fire), and function (shade, LW inputs) over time. Outputs will be used to discern the weight of the classification units (i.e., if units can be combined with similar outcomes over time such as LW recruitment, shade, disease and fire susceptibility). Thus, the most parsimonious classification system will result. Further, this initial screening of the classification system will also provide information on the limitations of the currently available field data and aid in the development of Phase 2.

Each classification system will be evaluated based on its ability to produce riparian classification units that meaningfully and reliably differentiate outcomes relevant to each FPHCP objective. The use of simulation modeling to estimate the mean residence times, and probability of transitions between alternative states in forest classifications under natural and human-caused disturbances for the purpose of forest planning and management has been used in eastern Washington (Shlisky & Vandendriesche, 2011) and northern Idaho (Teply et al., 2014). A report of this evaluation for each classification system will be presented to SAGE/CMER for feedback concerning accuracy, precision, uncertainty, and data gaps related to the preliminary classification system and their applicability and utility. Any changes requested will be incorporated into the classification system prior to the implementation of Phase 2. This discussion with the SAGE/CMER groups will also aid in the development of field protocols for data collection.

### *Phase 2*

In Phase 2, field data will be collected to assess the accuracy of the classification system within a diversity of riparian environments and geographic regions across eastern Washington (described in more detail in Phase 2, step 2), and remedy any data gaps identified in Phase 1. These data will be used to assess the accuracy and applicability of a given system for characterizing riparian forests based on FPHCP functional objectives and performance targets (Schedule L-1, Appendix N).

#### *Step 1: Field Data Collection and LiDAR Derived Data*

Field data collection will likely require a mixture of sampling techniques that quantify stand metrics, riparian functions, and site conditions. This will involve traditional ground-based techniques, and field data may also be supplemented with unmanned aerial vehicle (UAV) LiDAR-derived data (McGaughey, 2016, Moskal et al., 2017). More specific and detailed methods will be developed at the completion of Phase 1 after collaboration with and approval from SAGE and CMER. Examples of data needed for classification accuracy assessment, and for simulation modeling to assess the relationships between each classification unit and the FPHCP objectives, include, but are not limited to:

- **Canopy cover and stream shade**. This can be estimated in the field using a Solar Pathfinder, which can be used to assess the amount of solar radiation reaching an area throughout the course of a year. This device estimates the amount of radiation blocked by nearby objects and can estimate the percent effective shade by superimposing canopy images onto local sun path diagrams (Amaranthus et al., 1989). This method has been used to evaluate the Idaho riparian shade rules (Link et al., 2020). Other methods for determining canopy cover will be explored, such as densiometer readings, or hemispherical photography (Chianucci, 2020) following discussions with CMER and SAGE.

- **Groundcover composition**. Percent coverage in incremental sampling units moving away from the stream along transects. For example, in the EWRAP study field data was collected along a single 240-m transect run perpendicular to the stream beginning at the edge of the bankfull channel. Percent cover of groundcover species and identification of lifeform guilds (forbs, graminoids, shrubs, fungi, and bryophytes) will be assessed in multiple sampling plots dispersed equally apart along the transect. This will aid in quantifying changes in the riparian groundcover community and function with increasing distance from the stream. Groundcover species assemblages and associations can also be important indicator species for delineation of riparian habitat types (Barnes, 1985).

- **Stand structure and tree species composition**. In the field, this can also be recorded along each incremental sampling plot moving away from the stream. All trees will be identified to species, measured at breast height for diameter (DBH), and categorized for relative canopy position (understory, intermediate, co-dominant, dominant). Height and age of the most dominant trees along each transect will be estimated with a clinometer and increment core extraction from as close to stem base as possible, respectively. This will aid in estimating the dominant cohort initiation.

- **Standing dead and downed stems** will also be measured and tallied in the forested riparian area to aid in the potential for LW recruitment into the floodplain and stream. Deadwood size, characteristics, and decay classes will be recorded using standard accepted methods such as Brown's planar transect (Brown 1979).

- **Large wood** recruited into the stream, laying across the stream, or present in the flood prone area will also be quantified. In-stream LW size, volume, and function will be scored using methods similar to those described in Harman et al. (2017). When possible, source of LW input (e.g., bank erosion, windthrow) and distance of input from bankfull width will be quantified using methods similar to those described in Martin and Benda (2001) and Benda, (2002).

- **Topographical features** such as slope, elevation, and aspect will also be collected. These values can be derived from most standard DEM geospatial layers and validated in the field. For field validation, slope percentage will be estimated at multiple points along multiple transects perpendicular to the stream and averaged for the stand. Elevation will be estimated for the approximate stand center using a handheld GPS unit. Aspect will be recorded as azimuth in the downhill direction of the approximate stand center.

Sites will be chosen randomly within each stratum, defined by each classification system, using GIS tools such as Create Random Points. The number of sites selected for validation will depend on the number of strata created by the classification system and the coverage of each stratum in the resulting study area.

Regarding LiDAR-derived data, there is an abundance of literature describing and testing the application of different remote sensing techniques for evaluating forest structure and species composition. The application of LiDAR, satellite imaging, and aerial photographs in estimating riparian zone delineation, canopy cover and structure, understory structure, understory light availability, and species composition for upland and riparian forests are continuously being updated (Jarron et al., 2020; Michez et al., 2016; Moskal et al., 2015; Moskal and Cooke, 2015; Sparks and Smith, 2021; Wiggins et al., 2019). For example, Michez et al. (2016) found between 79.5% and 84.1% accuracy in classifying species compositions of riparian sites using small object-based image analysis (objects ca. 1 $m^2$). They found variables derived from spectral information (band ratios) to be the most appropriate in classifying species, followed by vertical structure variables. These techniques can be cross-referenced with aerial photographs and field work to increase confidence and assess accuracy for the region, respectively.

Moskal and Cooke (2015), in an assessment of the feasibility of using remote sensing to delineate and characterize riparian forests of Washington State based on the results of previous research projects and associated costs, ranked aerial LiDAR as the best option when compared to aerial imagery (National Agriculture Inventory Program; NAIP), aerial IFSAR (Interferometric Synthetic Aperture Radar), and high- and low-resolution satellite imagery (multiple sources). Following this assessment, Moskal et al. (2017) performed an intensive study of riparian vegetation classification and monitoring using LiDAR. This report also describes a protocol for field data collection for accuracy assessment of LiDAR modeling, methods for LiDAR modeling and accuracy assessment of riparian forest height, crown diameter, stand density, basal area, DBH, snag detection, conifer/deciduous classification, and LW; and methods without accuracy assessment for riparian area hydrology, canopy % cover, and vegetation class. Moskal et al. (2017) used the LIDAR processing software, Fusion (McGaughey, 2016) to create metrics for the study watershed. Fusion is a LiDAR analysis and visualization software that allows users to select and display subsets of large LiDAR data and contains several features and programs that facilitate direct measurements within the data cloud (McGaughey, 2016). Further, Wiggins et al. (2019) developed methods using FUSION that help increase the accuracy of LiDAR by combining field-based measurements in different topographic settings to develop a reference model of forest structure.

By evaluating the accuracy of the LiDAR data with fieldwork data in different topographic settings, the accuracy of different layers (overstory, understory, groundcover) can be assessed for the different settings. This might be sufficient to create a baseline of acceptable accuracy in assessing forest structure in different areas. Moreover, Jarron et al. (2020) developed a method of isolating the subcanopy point cloud of airborne LiDAR to model the understory structure more accurately. Their results show it is possible to use airborne laser scanning (ALS) to at least identify areas where understory tree volume and density are in transition of succeeding to different species, single species canopy replacement, or need thinning to lessen the threat of fire or disease. Finally, Sparks and Smith (2021) discuss the ability of ALS to classify individual tree species and estimate diameter at breast height (DBH), canopy position, height, and live/dead status using the Individual Tree Detection (ITD) algorithm ForestViewⓇ. Their results showed high classification accuracy of dominant tree species (>60%), within a study area. The accuracy assessment of individual tree attributes showed there was no statistical difference between ALS estimated tree height and DBH distributions, and field observed height and DBH distributions.

### *Step 2: Accuracy Assessment and Refinement*

Classification systems developed from the geospatial datasets during Phase 1 will be assessed for accuracy with the newly acquired field data and refined as needed. Accuracy assessment will employ traditional methods described by Goebel et al. (2001) which used the multi-factor classification system to delineate ecosystems of southwestern Georgia. In their study, Goebel et al. (2001) used a variation of canonical correspondence analysis (CCA) to confirm field-based classification and to measure the level of distinctness of each ecosystem type (i.e., classification unit). This process used a subset of the sample area data to conduct four canonical analyses using the CCA routine. The four combinations of data set analysis included 1) physiography and soil data set, 2) overstory and midstory species group data sets, 3) understory and ground-flora species group datasets, and 4) all ecosystem component datasets. This process was used to verify a classification by relating primary environment and vegetation matrices to a classification matrix (matrix of sample area and the classification unit it represents). This method of verifying classification units with field data could be applied to any of the classification methods described in Phase 1, step 2.

The newly acquired field data will also be used in another iteration of classification system development using the methods described above. This will involve updating and filling in any data gaps that were identified during Phase 1. The classification system can be seamlessly updated with new data as it becomes available. Following this update to the classification system another iteration of accuracy assessment will also be undertaken.

Simulation modeling will be used much as it was in Phase 1 to estimate how the classification units relate to FPHCP objectives over time. However, in Phase 2, we will explore a larger suite of modeling software and packages. Many simulation models have been developed to predict the long-term effect of silvicultural treatments on forest stand development and succession. For example, forest vegetation simulator (FVS) is a commonly used modeling software for forest planning and has even been used to generate trajectories and function of current stand conditions in the study area (Ceder et al., 2020; EMEP) and for riparian forests of western Washington (Pollock et al., 2012). However, several other modeling software packages that provide more robust results with similar data structure inputs have been developed. The following is a summary and review of currently available modeling packages.

ZELIG-CFS is a gap model, meaning it is a successional model that is well adapted for simulating the development of uneven-aged mixed forest types with complex structures. The model uses tree variables (DBH, species) and site variables (location, elevation, site index, etc.) to simulate individual tree growth, recruitment, and mortality and has been adapted for use in North American mixed forests and subtropical forests (Holm et al. 2012; Larocque et al., 2011; Larocque et al., 2019). In addition, it is commonly used to estimate the effects of different silvicultural treatments on forest development and successional pathways in Canadian forests (Searle et al., 2021). The benefit of this model is that it has been parameterized for the growth and development of species and covertypes common in eastern Washington (e.g., ponderosa pine, Douglas-fir). Further, it has been field tested with historical datasets and has shown a strong level of accuracy in predicting conifer species regeneration and development following human and natural disturbances (Elzein et al., 2020).

Other simulation modeling methods are also consistently being developed, such as F3, a forest change simulator that incorporates field inventory data from forest inventory analysis (FIA), forest vegetation simulator (FVS), landscape metrics, and remote sensing data (Huang et al. 2018). A benefit of F3 is that it incorporates field and remote sensing data with a traditional and accessible simulator. Another option for modeling the changes and succession of forested landscapes is in the LANDIS forest models. Developments for LANDIS-II allow for the inclusion of multiple factors (e.g., landscape, structural, climate change) that affect succession (Scheller et al., 2021). The benefit of the LANDIS simulation modeler is that it has been used in many studies of various landscapes and regions. For example, a recent publication has calibrated and validated its use for forest covertypes and terrain of the eastern Cascade Mountains (Furniss et al., 2022). Further, it can be adapted for different ecosystems and topographical features such as riparian zones (De Jager et al., 2019). It can separate the effects of disturbance and environmental factors to identify the drivers of succession and development over time (Wu et al., 2022). Finally, the Forest Projection and Planning System (FPS) is also an option for estimating changes in tree and stand metrics over time. The FPS software is especially useful when estimating forest productivity and would complement the Forest Productivity Modeling methods for classification system development. The FPS is commonly used as a predictor of forest productivity over time from site and vegetation characteristics and has specifically been applied to landscapes of the Pacific and Inland Northwest (Waring et al., 2006; Hemingway, 2020; Hemingway & Kimsey, 2020b).

The options discussed here for simulation modeling will be explored in their utility for estimating the future range of variability in stand structure and composition of the classification units defined by the classification system. The outputs from these models will thus be used to estimate the similarities in successional trajectories, and relationships to FPHCP objectives, (e.g., disturbance and disease susceptibility) for each classification unit under a no-management scenario and under disturbance scenarios reflecting historic anthropogenic and natural patterns. If two separate classification units show similar trajectories in succession and relationships to the FPHCP objectives, then the units will be combined, and another iteration of accuracy assessment and simulation modeling will commence.

Many of these models contain an option for estimating the effects of climate change on forest growth and structural development over time. While these options will be explored, we instead have proposed methods for developing a classification system that 1) incorporate stable landscape and ecosystem features (e.g., physiography and soil), and 2) can be seamlessly updated with new information (e.g., environmental factors and species compositions) as they become available (Pregitzer et al., 2001). In this way, the classification system can be amended in real time as changes in environmental conditions occur.

The classification system will again be evaluated by CMER based not only on their similarities and differences for riparian stand structure, development, health, and function but also on their ability to implement rules effectively. A report of this evaluation will be presented to SAGE/CMER for feedback concerning potential revision and assessment to address other concerns (e.g., utility, minimum threshold of performance). Based on the feedback received the next iteration of classification development, refinement, validation, and modeling may be undertaken.

## Project Risk Analysis

Potential challenges for completing Phase 1 of this study are associated with possible limitations with the existing geospatial datasets and/or riparian stand data. It is possible that some of the existing data sources will prove incomplete or not specific to the riparian zones. ETHEP Phase 2 will address data limitations identified in Phase 1 during field survey development. Risks in Phase 2 will arise from field data collection. Limitations to field data collection range from wildfire activity, landowner access denial, or general inability to fully sample forested riparian systems due to unforeseen circumstances. The level of field work required to validate the geospatial data sets and gather new information will depend on the results of Phase 1; thus, overall risk will become clearer upon completion of Phase 1.

### *Potential Limitations with Existing Field Data*

Existing field data from riparian stands (e.g., EWRAP data, FIA data, etc.) will be used to help explore and assess how well the GIS datasets address the study objectives. It is possible that the existing field data will have some deficiencies that may limit our ability to test the utility of the GIS datasets during initial classification system explorations. For example, the field data may lack certain stand metrics or other methods/details that would be helpful for characterizing riparian stands. This could cause the sample sizes for each classification unit to become too small to adequately assess the accuracy of each unit with confidence. These issues will be minimized by conducting targeted field surveys during Phase 2 specifically designed to evaluate our metrics of interest and address the greatest areas of uncertainty identified in Phase 1.

### *GIS Data Compatibility with Study Objectives*

The publicly available GIS datasets may lack certain characteristics, resolutions, or information important for addressing the study objectives. For example, the existing datasets generally cover the entire landscape (upland and riparian environments), so they may not always capture the level of detail desired for riparian forests, which occur as narrow linear features on the landscape. These issues will be ameliorated by rejecting datasets that do not meet the study criteria and by modifying, supplementing, and combining the existing datasets to ensure alignment with study objectives.

### *Collection of Field Data*

One risk involved with Phase 2 field data collection is access to, and availability of multiple sites for each classification unit. Many land parcels that are subject to management under the FPHCP objectives are owned by private citizens or industrial timber companies. Despite this potential limitation, an ideal classification system will contain a relatively low number of classification units to provide efficient implementation of management – mitigating access issues. For example, from our review of other states and governing entities, classification units usually fall between four (Idaho) to six (Oregon) general categories which can be further divided based on special circumstances (e.g., protected species, rare landform characteristics). Further, the criteria for classification units to be accepted requires ample size (e.g., > 1 ha), and repetition throughout the study area. If access limitations persist, preventing adequate field sampling for classification, we will consider supplementing field data with remote sensing products (e.g., Lidar, satellite imaging, etc.).

### *Task Breakdown*

Table 2. Proposed time allocation for implementation of study plan after approval from ISPR review. *Hours for field data collection expected to be divided among a three-person field crew for one field sampling season.

| **Phase/Step** | **Description** | **Hours** | **Deliverable** |
|---|---|---|---|
| Phase I, Step 1 - Evaluation of Available Datasets | -Evaluate available datasets for effectiveness in describing riparian stand structure, function, health, and fire regime | 400 | Written report listing the potential of available datasets to be used in riparian forest characterization and delineation. |

|  |  |  |  |
|---|---|---|---|
| Phase I, Step II and III - Framework Development | -Develop riparian classification units as a function of identified datasets.<br>-Evaluate relationships of classification units with FPHCP objectives.<br>-Engage with CMER/SAGE | 440 | Present results from classification system development in written report that includes description of datasets used, maps of proposed habitat classification units, outputs from modeling scenarios used to refine number of units. Engage in discussion with SAGE/CMER for feedback. |
| Development of field manual and data collection protocols prior to initiation of Phase II | -Develop field manual and data collection protocols for project implementation | 300 | Written document describing methods for field data collection for accuracy assessment of classification system and supplementation of existing datasets. |
| Phase II, step I - Field Data Collection | -Identify sampling locations<br>-Conduct field sampling using field manual and protocols | 1400* | Map of sampling locations. Data formatted for accuracy assessment analysis. Written description of data characteristics and spatial coverage. |
| Phase II, Step II - Refinement of Framework & Final Documentation | -Validate Phase I riparian classification units using field collected data<br>-Develop final riparian classification system<br>-Engage with SAGE/CMER | 360 | Written report of methods and results of data analysis, and refined classification system. This includes discussion of the results with justifications for refinement, and map(s) of classification units in the study area. |
| Quarterly progress reports.<br>Attend meetings and discussions with SAGE/CMER | -Reports provided every quarter of work completed<br>- 1-2 hour monthly/biweekly meetings/conference calls as needed | 144 | Written report detailing work completed at the end of every quarter and projection of work to be completed by next quarter.<br>Meetings with SAGE/CMER to discuss project progress, and feedback on interpretation of results. |
| **Total:** |  | **3044** |  |

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# Appendix I[2]

# Literature Review

The following is a review of the most relevant literature addressing the factors driving riparian forest function, health and development, and natural riparian forest disturbance. The five key riparian functions described in this review (shade, large wood and litter input, sediment, and nutrient retention) are those identified as most important in the Forest Practices Habitat Conservation Plan (FPHCP, 2005). This review is intended to provide context for the Eastside Timber Habitat Evaluation Project (ETHEP) study design and its role in informing the Eastside Rule Group Critical Question, Will the application of the prescriptions result in stands that achieve Eastside FPHCP objectives (forest health, riparian function, and historical disturbance regimes)?

This review will focus primarily on studies conducted in areas with similar habitat characteristics as eastern Washington (e.g., the Intermountain West Region, Southern Alberta, and British Columbia, Canada). However, to be comprehensive, this review will also include any generalizable conclusions or correlations from several studies conducted outside of this region focusing on the effects of management on riparian functions. Three important studies recently completed in western Washington are the Type N Experimental Buffer Treatment Study on incompetent (soft rock) lithologies (hereafter referred to as the “Soft Rock” study; Ehinger et al., 2021; CMER 2021.08.24), and the Type N Experimental Buffer Treatment Study on competent (hard rock) lithologies (hereafter referred to as the “Hard Rock 2018” or “Hard Rock 2021”; McIntyre et al., 2018;2021; CMER 18-100; 2021.07.27), and the Westside Type N Buffer Characteristics, Integrity, and Function Study (hereafter referred to as the BCIF study; Schuett-Hames et al., 2019; CMER 2019.10.22.B). The Hard Rock study compared the effects of different retention buffer widths (no harvest, 50-foot buffers, < 50-foot buffers, and clearcut to stream) on the five key riparian functions. The Soft Rock and BCIF studies compared the current forest practices rule of 50-ft no-cut buffer for at least 50% of non-fish bearing stream length to no-harvest reference sites. The Hard rock and Soft Rock studies utilized a before-after-control-impact (BACI) experimental design. The BCIF study utilized a control-impact design due to a lack of available pre-harvest data.

### *Shade*

Canopy cover provides shade for streams that decreases the amount of incoming incident radiation and thus regulates stream temperatures. Temperature regulation is vital for sensitive salmonid fish species that require cooler waters, and shade is often the primary function assessed when developing state regulations (Groom et al., 2011; Groom et al., 2018; Teply et al., 2014). The importance of shade and cooler in-stream temperatures for fish habitat have been thoroughly investigated (Bjornn & Reiser, 1991; Chapman & Bjornn, 1969; Ebersole et al., 2001; Sullivan et

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al., 2000). The streamside shade will likely become even more critical with the predicted increases in air temperature over the next century (Manuta et al., 2009). For example, Cristea and Burges (2010) modeled expected stream temperature increases for three streams in the Wenatchee River basin of eastern Washington. Their results suggest that if vegetative cover remains constant over the next century, stream temperature will likely increase by 2.5 – 3.6º C in the warmest reaches by 2080. However, increases in mature streamside vegetation that can produce a dense canopy may ameliorate these impacts, especially in smaller streams. For example, the model Cristea and Burges (2010) used predicted that dense streamside vegetation could reduce water temperatures as much as 1.5 – 2.8º C in smaller tributaries but only as much as 0.3º C in the larger Wenatchee River. In another example, Wondzell et al. (2019) modeled future climate scenarios and varying vegetation covertypes (post-fire herbaceous, young open riparian forests, and mature riparian forests) and their interacting effect on stream temperature. Based on this model, they found that shade was the most influential factor affecting stream temperatures. They concluded that increasing shade percentage along streams could reduce future stream temperatures below current levels even with projected air temperature and stream discharge source temperature increases expected from climate change.

While stream temperature is initially reflective of moisture source (snowmelt, liquid precipitation) and watershed subsurface soil characteristics, as water flows downstream and into higher-order streams, the net rate of temperature gain or loss is the additive sum of incident radiation, evaporation, conduction, and advection (Brown, 1983; Bescheta et al., 1987). Bescheta et al. (1987) present evidence that solar radiation inputs are of the highest importance to the stream's net heat exchange rate per unit area compared to other factors. Within the net heat exchange calculation, the heat released from evaporation generally cancels out the heat gained from warm air temperatures (convective and advective heat transfer). Thus, temperature fluctuations are expected to be more severe in less-shaded/more-exposed streams. This theory has been supported by many experimental field and simulation studies showing evidence that canopy cover reduction leads to a significant increase in peak summer stream temperatures primarily due to the increase of incoming solar radiation. For example, Bescheta and Taylor (1988), in a 30-year study (1955-1984) of the Salmon Creek watershed, found a considerable increase in stream maximum and minimum temperatures (6 ºC and 2 ºC respectively) following harvest despite only a slight decrease in maximum air temperatures during the same period. The only significant relationship between the stream temperature increases was found with a cumulative index (total area logged each year) of forest harvesting ($p < 0.001$). Sridhar et al. (2004) developed an energy balance model based on field data and regional low-flow. They observed temperature maximums from multiple watersheds on the eastern and western slopes of the Cascade Mountains. The authors found that leaf area index and tree height (directly related to shade) strongly affected maximum stream temperatures. Gomi et al. (2006), in an experimental field study of headwater stream temperature responses to riparian harvest treatments, found a significant increase in daily maximum in-stream temperatures for streams adjacent to clear-cut riparian areas relative to control streams with adjacent 10 m and 30 m no-cut buffers.

Further, the variations in temperature response within the clear-cut streams were consistent with differences influencing exposure to incoming solar radiation (e.g., channel morphology, orientation). DeWalle (2010) developed a theoretical model that explored the impacts of buffer width, height, and density on direct beam solar radiation penetration to stream surface. Their results showed evidence that tall buffer heights (≈ 30 m) and dense canopies (≈ 6 m leaf area index) could maintain at least 80% of the shade on smaller streams (6 m wide) regardless of orientation, even with relatively narrow buffer widths (12 m). However, results from the Soft Rock, Hard Rock, and BCIF field studies of buffer treatments in headwater streams of western Washington showed that canopy cover decreased for four years after harvest because of the increase in tree mortality in riparian buffers (primarily due to windthrow in all studies). In the Soft Rock study, canopy closure began to recover after post-harvest year 4. The recovery rate was proportional to the size of the retention buffers, with the 50-foot buffers recovering more quickly than the < 50-foot buffers and no buffer (clear-cut) treatments. The loss of canopy cover and, thus, the size of the retention buffers was proportional to the increase in summer temperatures for all studies. The Soft Rock study concluded that the buffers of harvested sites did not prevent increases in summer stream temperatures over the time of the study. The BCIF study found that the canopy cover percentage of the treatment sites recovered to similar values as the reference sites after ten years.

While many studies have quantified and compared the effects of harvest intensity, percent canopy reduction, and buffer height and width on stream temperature, it is important to acknowledge that other factors, such as stream size and stream order, can impact the effectiveness of these treatments. For example, Feld et al. (2018), in a literature review of stressors in river ecosystems, concluded that a buffer width of 30 m on either side of the stream would maintain instream temperatures relative to fully forested watersheds; these results were dependent on stream size. The most effective shading prescriptions for maintaining stream temperatures were for streams < 5 m in width. Moreover, they derived from studies by Collier et al. (2001) and Macdonald et al. (2003) that buffer length correlates with reduced stream temperatures, especially in headwater streams. Further, thinning operations not only increase local stream temperatures but have also been shown to increase maximum downstream temperatures and thermal variability (Roon et al., 2021). The results of these studies suggest that the efforts to reduce stream temperatures with vegetation are essential not only in larger fish-bearing streams but also in headwater and lower-order tributary streams that ultimately feed into the fish-bearing streams.

### *Large wood (LW) and litter*

Large wood in streams is essential to create pools, regulate flow, and provide a slow pulse of nutrients that help create and maintain salmonid habitat (Harmon et al., 1986). Sievers et al. (2017), in a global meta-analysis of the effects of riparian alteration on trout populations, found the most positive response of trout populations was with increasing in-stream wood and livestock exclusion from the riparian area. Their results showed some evidence that increasing in-stream large wood and litter recruitment may attract fish instead of increasing local populations.

Large woody debris production and recruitment into streams can vary between watersheds, and multiple studies have attempted to identify the drivers of LW production with varying results. For example, Benda et al. (2003) present a wood budgeting framework for riparian zones that includes numerical expressions for punctuated forest mortality by important drivers they identify as fire, chronic mortality and tree fall, bank erosion, and mass wasting, decay, and stream transport. This framework can be applied to different regions by adjusting parameter values to make predictions of the importance of landscape factors (e.g., climate, topography, basin size) on wood recruitment and abundance in streams for any area. Depending on the region or landscape for which the framework is being applied, less common but more locally important disturbances such as ice storms, ice breakage, and wind throw can also be incorporated. This study and the framework it developed illustrate the diversity of the wood recruitment, transport, and decay processes. The relative importance of each wood recruitment mechanism, and the fate and transport of the in-stream wood, depends on the variation observed in the environmental, management, and vegetation factors of a particular area of interest. Thus, frameworks such as the one developed by Benda et al. (2003) help identify the relative importance of these recruitment processes and their relationship with local landscape factors.

In the western United States, several notable studies over the past two decades have investigated the factors theorized to affect LW recruitment. For example, Hough-Snee et al. (2016) compared woody debris frequency and volume in streams with multiple riparian, geomorphic, and hydrologic attributes to determine which characteristics had the strongest correlations and thus were theorized as drivers of LW in streams. They analyzed the in-stream wood volume and frequency data for seven interior Columbia River Basin sub-basins. The strongest predictors of LW frequency in streams were precipitation, riparian zone big tree cover, and watershed area. Ross et al. (2019) found that the mechanism of LW recruitment in streams differed by stream size, with recruitment by erosion being more common in large streams and windthrow being more common in smaller streams. This is consistent with the results of the BCIF, Hard Rock, and Soft Rock studies that found the predominant source of LW input (for small-non-fish-bearing streams of western Washington) was from windthrow disturbance in the riparian treatment buffers. Their results also showed that pool formation from LW was most common when conifers dominated the riparian area over deciduous trees. Lastly, channel confinement was the most influential predictor of wood-formed pools, with fewer wood-formed pools in more confined reaches. The authors (Ross et al., 2019) determined that wood-formed pools in this region (Southeastern Alaska) were from relics of pre-harvest recruitment (i.e., not a result of management prescription). Conversely, the Hardrock study showed evidence that even small pieces of wood resulting from recent harvests were important in pool formation.

Sobota et al. (2006,) in a landscape-wide study of factors affecting tree fall direction and LW recruitment in watersheds of the Pacific Northwest, found valley constraint to have the strongest correlation with in-stream woody debris. Riparian areas in channels with >40% valley side slopes had the highest tendency for tree fall towards streams; in these steep slope valleys, recruitment of large wood in streams was 1.5-2.4 times greater than on moderately sloped landforms (< 40%). Wohl (2020), in a review of studies on LW controls, suggests a climate-controlled balance between site forest primary productivity and decay rates of downed wood are the first-order controls on in-stream LW loads. The authors list disturbance regimes and recruitment mechanisms (e.g., hillslope gradient) as the second-order controls on in-stream LW loads.

Before the above studies were conducted, a technical document, Review of the Available Literature Related to Wood Loading Dynamics in and around Streams in Eastern Washington Forests, was developed for CMER (CMER 03-308, 2004). In this review, the researchers sourced 14 references with quantitative and descriptive information relating to the correlation between wood volume and pieces of wood in streams and the adjacent riparian community. The authors conclude that while the literature is incomplete, several significant correlations existed between LW in streams and riparian zone stand characteristics. For unmanaged (defined as unlogged and un-roaded) sites in Washington, researchers reported positive correlations between the volume of LW in streams with adjacent riparian zone mean tree height ($P<0.001$), mean tree diameter ($P<0.001$), and mean basal area ($P<0.001$). For numbers of LW, positive correlations were found with the basal area ($P<0.007$) but no other vegetation characteristic of the adjacent riparian area. However, when regression analysis was performed on LW piece quantity with the core zone (30 ft beyond bankfull width), a significant positive correlation was found with core zone trees/acre ($P<0.001$, $R^2 = 0.45$) and core zone basal area/acre. Relative to managed riparian areas, streams adjacent to unmanaged riparian areas had significantly higher LW volume. The most relevant sources of these results listed in this review were from Fox (2001), Chesney (2000), Camp et al. (1997), and Knight (1990). Two other studies named in this review (McDade et al., 1990; Fox, 2003) show evidence that as much as half of the wood found in the streams could not be attributed to the adjacent, designated riparian areas suggesting that further studies of LW drivers should focus on basin-wide study areas.

Multiple studies have also investigated the effects of timber harvest under varying riparian management zone prescriptions on LW recruitment. Specific to eastern Washington, Schuett-Hames and Stewart (2019) found that riparian management zones under the current standard shade rules (SR) for fish-bearing streams in the mixed conifer habitat type (2500 - 5000 feet elevation) had differences in instream LW recruitment relative to unharvested reference sites ten years post-treatment. The SR sites had, on average, four times higher LW recruitment than the unharvested reference sites. Proportionally, SR sites also had higher LW recruitment from greater distances to the stream. These results suggest that while treatment of SR sites is intended to increase resistance to disturbances such as fire and disease, it also increases the susceptibility to windthrow and thus increases mortality relative to reference sites five years post-harvest. It is important to note that this was a short-term study (10 years). The authors note that LW recruitment is a process that can change over decadal time scales, and follow-up monitoring is recommended.

In several headwater streams of western Oregon, Burton et al. (2016) used field experiments to determine the effects of various no-harvest buffer widths and basin geomorphology on instream wood loading. The authors compared in-stream wood recruitment in areas with upland thinning densities ranging from 85 to 200 trees per hectare within areas of no-harvest riparian buffer widths ranging from 6 m, 15 m, and 70 m. Their analysis utilized a hierarchical linear mixed model with repeated measures that examined the relationships between instream large wood volume, buffer width, and reach and stream basin-level variables (e.g., basin area, stream gradient, stream width, etc.). While there was some evidence that a decrease in buffer width led to an increase in instream wood, the only significant relationship was with the drainage basin area. For every 1-hectare increase in the basin area, there was a 0.63% increase in instream wood volume per unit stream length. The Soft Rock, Hard Rock, and BCIF studies in western Washington showed that in-stream wood counts increased adjacent to riparian management buffers relative to unharvested reference sites. All studies attributed the increase of in-stream wood to the increase in mortality primarily due to increased windthrow. The highest in-stream wood counts were for the widest retention buffers (50 feet) and lowest for the clear-cut (no buffer) treatments. However, the clear-cut (no buffer) treatments had the highest counts of smaller (mostly slash) wood.

Another function of the riparian zone is the important source of nutrients and habitat development from litter inputs. However, there appears to be a lack of experimental studies investigating the factors affecting litter delivery into streams. Only two studies, one from western Washington and one from western Oregon, were found. Bilby and Heffner (2016) used a combination of field experiments, literature review, and modeling to estimate the relative importance of factors affecting litter delivery from riparian areas into streams of western Washington in the Cascade mountains at high and low elevations. Their results showed that when the slope of the riparian area increased from 0º to 45º, the width of the litter-contributing area increased by 71-95%. This was also dependent on stand age, with mature forests, on average, showing a 35% greater contributing area than sites dominated by younger trees. The larger contributing area in mature forests was attributed to the mature stands having taller trees than the young stands (i.e., taller trees increase the contributing area). Based on this study, slope, stand structure, and tree height are the most critical factors in determining the effective buffer width for in-stream litter input potential. Other than stand structure and topography, another study shows evidence of species composition affecting litter delivery into streams. Hart et al. (2013) compared the difference in litter delivery into streams between riparian zones dominated by deciduous (red alder) and coniferous (Douglas-fir) tree species in western Oregon. They found that litter input into streams was significantly higher in grams per meter per year for riparian forests dominated by deciduous forests (red alder) than for riparian forests dominated by coniferous species (Douglas-fir). The timing of the inputs also differed, with the greatest differences occurring in November during autumn peak inputs for the deciduous forests. Lateral litter movement in the riparian area increased with slope for deciduous riparian forests throughout the year and for coniferous forests only in the spring and summer months.

Aside from factors affecting litter input, Kominoski et al. (2011) found that riparian forest species composition can also affect the rate of litter decomposition and, thus, nutrient release within streams of the Pacific Coast Mountains of southwestern British Columbia, Canada. The results of this study show that the decomposition rates of Alnus rubra litter were significantly higher in streams of riparian forests dominated by deciduous trees than in coniferous or mixed riparian forests despite similar invertebrate and microbial communities. These results suggest that forest canopy composition influences invertebrate feeding activity and the interactions between invertebrates and the microbial community.

Overall, most of these studies point to riparian forest productivity (e.g., tree height and tree density), slope, and species composition (deciduous vs. coniferous) as the most critical drivers of organic matter (LW and litter) input into streams. The results of these studies suggest that as productivity and area of watershed increases, so does the potential for recruitment. Also, as the slope of the watershed increases, the contributing distance of organic matter to the stream increases. However, several of these studies show that the mechanisms important for estimating LW recruitment (disturbance type and severity) depend on other characteristics such as stream size, channel confinement, and management prescription history. In very general terms, the literature suggests that the potential of LW and litter recruitment into streams can be increased by increasing basal area, large tree density, and extending buffer widths relative to increasing slope.

*Sediment and nutrient inputs*

The function of riparian areas to regulate and filter the flow of sediments into streams is essential not only for water clarity and pool formation but also because sediments can carry nutrients and pollutants with them as well (Cooper et al., 1987; Hoffman et al., 2009; Polyakov et al., 2005). Depending on the landscape context of the riparian area, for example, adjacent uplands used for agriculture or industry, the relative importance and impact of the riparian buffer on sediment and nutrient transport can differ considerably.

Timber harvest and buffer prescriptions can greatly impact the magnitude and timing of sediment transport. Karwan et al. (2007) conducted a before-after control-impact (BACI) experiment in Mica Creek ID to test the effects of timber harvest on suspended sediments in streams following timber harvest. One watershed was clear-cut outside the 75 ft buffer, and one was partially cut outside the RMZ. The partial cut showed no difference in suspended sediments compared to the reference (no harvest), and the clearcuts showed a short-term increase in sediment loads. This study shows evidence that sediment fluctuations can be impacted based on harvest treatments outside of the buffer zones. The complexity of the riparian buffer can also contribute to the effectiveness of sediment retention. Feld et al. (2018) concluded from their synthesis of field experiments on buffer characteristics that adjacent stream buffers of grasses and herbaceous vegetation 3 m - 8 m wide were more effective at retaining sediment than high tree height, dense canopy buffers. This suggests a trade-off between stream shade and understory productivity; thus, depending on habitat preferences, the movement towards larger older trees with somewhat open canopies to stimulate understory productivity may provide healthier stream and riparian zone habitats. In the headwater studies of western Washington, the impact of forest harvest in buffered areas relative to reference areas on sediment transport gave mixed results. Many of the treatment streams of the BCIF saw an increase in sediment transport relative to reference streams, which was attributed to the increase in uprooted (windthrown) trees. In all studies, sediment transport increased with weather events. However, multiple confounding factors made drawing firm conclusions difficult, such as extended dry periods before harvest and extremely rainy periods following harvest and the incidence of mass wasting events upstream in reference basins. In comparing the Soft Rock and Hard Rock studies, Ehinger et al. (2021) reported that the suspended sediment data shows that the marine sediment lithologies were more erodible than the competent lithologies of the Hard Rock studies. These results suggest that factors such as soil and parent material of the riparian area can affect the amount of sediment export following treatment. As for nutrient export, all studies found similar results of an increase in nitrogen concentration and export that correlated negatively with the proportion of stream buffered (less buffered = greater increase in exports). These results were mainly attributed to the reduction in uptake by vegetation.

In the Intermountain West basin geology, hydrologic/climatic regimes, stream order, position in the landscape, and channel material can all influence sediment supply and, thus, sediment flux from direct and indirect harvest effects. Most studies attribute hillslope and vegetation cover as the main controlling factors of stream sediment delivery. For example, Bywater-Reyes et al. (2018) found that the variation of sediment yields over 60 years in the H.J. Andrews experimental watershed in the western Cascade Range of Oregon was explained mainly by the watershed slope. This suggests that watersheds with high slope variability may have higher variability in sediment yield following disturbance (e.g., harvest). These results are similar to those found by Hook (2003) in an experimental analysis of factors affecting sediment transport into streams of rangeland systems. They found that slope and vegetative cover in the riparian zone were the most substantial factors affecting sediment retention. Their findings suggest that buffer widths of > 6 m effectively retained 94% - 99% of sediments when the buffer consisted of dense vegetation cover. The type and height of the vegetation present were less important than biomass, cover, and density. Sediment input in this study was most significant for sparsely vegetated streams with narrow valley widths and steep slopes.

Natural disturbances such as fire can also heavily influence sediment and nutrient delivery into streams. Depending on the severity of the fire and the following weather conditions, the increase in sediment and nutrient flux into streams post-fire can vary. Position in landscape and basin geomorphology can also compound or ameliorate the effects of fire. For example, Crandall et al. (2021) found a 2,000-fold increase in sediment flux and a 6,000-fold increase in particulate carbon and nitrogen flux in streams of a semi-arid forested watershed of Utah that was affected by a mega-fire followed by an extreme precipitation event. However, regardless of fire severity or burned vs. unburned, a watershed modified for agriculture or urbanization showed an overall higher nutrient concentration, further exacerbated by the fire/precipitation event. This study suggests that riparian zone management should consider its proximity to agricultural and urban land use projects. Reducing the potential for high-severity fire may be more important in an anthropogenic shared watershed than in “natural” watersheds.

The changes in stream community following fires via changes in sediment, nutrient, and light penetration can also have varying effects on fish habitat. For example, Cooper et al. (2015) found that changes to the Santa Barbara County, California region's river communities one-year post-fire resulted in the extirpation of southern California steelhead trout regardless of fire severity. On the other hand, Harris et al. (2018), in a study of post-fire effects on the Salmon River Basin, Idaho, found that fires in tributary streams resulted in debris flow changes that increased the magnitude of invertebrate biomass exports into the main channels. These increases in biomass (2-3x those of unburned tributaries) lead to a stronger selection by trout for burned confluences. This study implies there can be beneficial impacts of fire in headwater riparian zones on fish habitats via prey export into the main channel.

Considering the expected increase in fire frequency and intensity, many researchers recommend active management to ameliorate disruptions to natural fire regimes in the main channels supporting sensitive fish species (Prichard et al., 2021; Ren et al., 2022). While many riparian zone prescriptions might aim to restore structure that emulates historical fire regimes, Churchill et al. (2022) stress adapting fire-prone ecosystems to future climate conditions (future range of variation – FRV) instead of historical reference conditions. The future range of variability that drives increases in the need for more resistance and resilience of fire-prone (i.e., drier) ecosystems due to future climate changes might involve forests with more open and less complex canopies and move towards a structure of fewer and larger trees.

### *Riparian Health*

Silvicultural treatments can improve stand health and structural development and influence successional pathways. When appropriately applied, stand thinning can reduce stand susceptibility to insects, disease, and fire and increase the diameter growth rate for large trees (Fiddler, 1989; O'Hara, 1988; Zhang et al., 2013). The specific prescriptions can vary depending on region and desirable objectives (e.g., fire resistance, biodiversity increase, growth). Targets for the inner and outer zones of the eastern Washington RMZs incorporate structure and density to theoretically support the health and development of the riparian stand and protect stream function (FPHCP, 2005, chapter 4b; Appendix N Schedule L-1). In many cases, tree retention targets for riparian zones are estimated in simulation and field experiments for their efficacy in providing shade, temperature regulation, and material input (discussed above). However, the scientific basis for these targets from a silvicultural perspective is unclear. For example, Dwire et al. (2010) review and discuss the potential effects that fuel reduction treatments within riparian zones can have on function and the riparian area's vegetation structure, terrestrial habitat, and soil chemistry. The authors list management implications for riparian zone fuel reduction treatments in their review. Most of these suggestions focus on the inherent effects on function (e.g., shade, LW, etc.), but one relevant to the topic of riparian vegetation and structure states, "Objectives for fuel 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 conditions of uplands and riparian areas."

There is a paucity of riparian zone silvicultural studies across North America. Clear cutting to the stream bank was common practice in the Pacific Northwest through the late 1970s (Richardson et al., 2012), and 40-50-year-old stands are just reaching the age where the effects of thinning can be assessed. No studies that have tested or theorized preferred silvicultural practices and treatments specific to riparian areas on forest stand development in the Intermountain West could be found in the literature. In our search, we did find a few riparian silvicultural recommendations that focused on the eastern U.S. and central Canada, and even fewer that focused on the coastal region of the western United States. In both regions, thinning experiments have shown evidence of changes in regeneration compositions of early and late successional species in the groundcover and understory layer in the years immediately following thinning. However, we lack long-term thinning studies in riparian areas. Post-treatment monitoring of preferred species compositions and undesirable species invasion would provide further insights into the effects of thinning prescriptions on groundcover development.

While there is a lack of studies addressing thinning within RMZs and its effect on riparian stand development, a handful of studies have assessed the impacts of thinning within RMZs on riparian forest ecological characteristics and functions. For example, Anderson and Poage's (2014) density management and buffer study in western Oregon applied multiple thinning treatments to young and previously unthinned (50 – 80 yr. old) Douglas fir stands adjacent to headwater streams. The unthinned control contained ~500 – 865 trees ha $^{-1}$, and treatments were separated into three density retention groups: heavy (~297 trees ha $^{-1}$), moderate (~198 trees ha $^{-1}$), and variable residuals in equal thirds (~99, 198, and 298 trees ha $^{-1}$). Treatments were applied with four different no-cut buffer widths: two tree heights (110-146 m), one tree height (55-73 m), variable width (15 m min; 22 m avg), and streamside retention (6 m minimum). Effects on amphibian and aquatic-riparian vertebrate fauna habitat and riparian microclimates and microsites were assessed. This study showed thinning to have little effect on habitat quality and microclimate unless there was an adjacent patch clearing greater than 0.4 ha. A caveat to this study is that sites were only located on federal lands and narrow non-fish-bearing headwater streams, and all inferences were constrained to the first ten years following thinning. Further, this design did not test the effects of the thinning treatments on stand structure and development over time.

Other important data findings from the Anderson and Poage (2014) study not presented in the paper were also published in a brochure outlining preliminary results of the *Density Management and Riparian Buffer Study in Western Oregon* that thinning did increase average tree growth, tree regeneration, and species richness in the herbaceous and shrub communities (Mazza, 2009). The increase of thinning (unthinned control, 200-350 trees per acre; high-density thinning, 120 trees per acre; moderate density retention, 80 trees per acre; variable retention 40/80/120 trees per acre with 10% cut in circular gap openings) and the inclusion of gaps increased the proportion of early seral species to late seral species. These results reflect short-term changes, and their projection into the long term is unclear. Further, these differences were not statistically analyzed, and the trend may be affected by random chance or other unknown variables. This study is ongoing and long-term results of different thinning designs outside of variable width no-cut buffers have not yet been evaluated (Chan et al., 2004).

In the Lake States region of the mid-western U.S., a series of thinning experiments were conducted in riparian zones to determine their effect on regeneration, biodiversity, and stand development. Kastendick et al. (2014) surveyed the understory community before and after different harvest treatments in forested riparian areas of northern Minnesota. Their results showed that increased overstory harvest (lower residual basal area) led to higher early successional species regeneration densities. Regeneration densities of late-successional species showed no difference in treatment. However, they were subjected to higher levels of competition by shrubs and early successional species in the high harvest/low residual basal area treatment.

Palik et al. (2012) found similar results of an increase in early successional species and shrubs with an increase in thinning intensities. They also found a higher reduction of basal area via an increase in mortality in the higher intensity thinning plots due to increased incidents of windthrow. Zenner et al. (2013) showed some change in the composition and an increase in species richness of the herbaceous community of RMZs post-thinning, but their results did not show a change by treatment over time. Slightly north of these studies, Mallik et al. (2014) compared woody plant (tree and shrub) regeneration among different harvested gap sizes (small, 10 – 20 m2, medium, 21-100 m2, and large, > 100 m 2) and between harvested and unharvested boreal mixed-conifer riparian buffers of central Canada. Again, their results were very similar, with higher regeneration densities in harvested buffers compared to unharvested buffers seven years post-treatment. They also found a trend of higher regeneration densities within medium and large gaps relative to small gaps. There was also an increase in species diversity and the presence of early-successional species in larger gaps relative to smaller gaps and unharvested buffers. The methods and investigations of these studies present interesting results to consider in choosing residual targets for RMZs of different covertypes. However, considering the difference in the region and climate, the results should not be expected to translate to the different ecosystems and species assemblages of the Intermountain West.

### *Disturbance (fire)*

The general goal of the Forest Practices Rules is to meet the 4-goals of the Forest and Fish Report: to provide compliance with the Endangered Species Act, restore and maintain riparian habitat, meet requirements for the Clean Water Act, and keep the timber industry economically viable (FFR 1999). This requires implementing prescriptions that balance timber production and land use with “natural” forest function. Land management philosophies throughout the West are shifting from focusing exclusively on fire suppression and maximizing timber production to more “intentional management” (proactive thinning and, thus, many timber harvest prescriptions) that (eastern Washington included) seek to emulate historical disturbance regimes that drive forest ecosystem development and succession (Schimel & Corley, 2021). It is important to note that other disturbances (e.g., windthrow and ice damage) also influence forest structure and composition. However, this review will focus on fire as the most influential natural disturbance affecting forest structure and species composition in eastern Washington's semi-arid and arid landscapes.

As discussed above, wildfires within the riparian zone can potentially affect the five key functions (shade, LW, litter, nutrient, sediment) over short and long periods. However, there is evidence that the incident of fire and the smoke it produces can cause immediate and short-term changes to physical stream attributes such as temperature and light availability. For example, Sanders et al. (2022) Investigated the immediate and short-term effects of wildfire within a riparian zone on water temperatures and dissolved oxygen levels, as well as light availability and air temperatures in headwater streams of western Oregon. Higher burn severity correlated with increasing daily maximum stream temperature by as much as $4.5^{0}$ C and a decrease in dissolved oxygen (DO) by 16.9% on the day of the fire. The week following the fire, smoke decreased available light, the stream temperature maxima, and the available DO. Although minimal effects on stream aquatic biota were detected in this study, it demonstrates the potential effects of wildfire smoke on physical stream characteristics (e.g., temperature, light, oxygen).

Fire frequency and severity in the riparian zone can be more idiosyncratic than in upland forests. Dwire and Kauffman (2003) list multiple characteristics of western US forested and rangeland riparian zones that influence the behavior and spread of fire differently than in adjacent uplands, even if the dominant covertype and age structure are the same. Relative to adjacent uplands, the authors list the following potential characteristics: (1) higher fuel loads because of higher net primary productivity, (2) higher fuel moisture content due to proximity to water, shallow water tables, and dense shade, (3) active channels gravel bars and wet meadows may act as fuel breaks, (4) topographic position (canyon bottoms, low point on landscape) leads to higher relative humidity, fewer lightning strikes, but more human-caused ignitions, (5) microclimate may lead to cooler temperatures and higher humidity that can lessen fire intensity and spread. Generally, these factors lead to an overall length but more variable fire return interval in riparian areas than adjacent upland systems, at least in the Pacific Northwest (Olson, 2000).

Everett et al. (2003) investigated the frequency of fire disturbance in forested riparian areas relative to upslope forests. They surveyed multiple valley types, plant association groups, and aspects to determine the relative impact of these physiographic features in determining the continuity in fire intensity and frequency of riparian areas and upland slopes. These analyses were conducted on streams in the Okanogan and Wenatchee National forests that are Douglas-fir dominated, and the fire history was reconstructed from available fire scars. In general, results showed lower fire frequency, based on fire-scar records, in the riparian areas than on sideslopes, regardless of aspect or plant association groups. However, the difference between riparian area fire events and sideslope fire events was most significant for western aspects and least for northern aspects. Also, riparian areas with eastern and western aspects had more fire events than those with northern and southern aspects. The authors speculate that the lower number of fire scars available in the riparian areas relative to upper sideslopes may not be indicative of lower fire frequency but may be a result of higher intensity fires that killed stems when fires did occur or are indicative of fewer surface fire encroachments into the more mesic riparian areas. The probability of fire occurrence creating a new cohort (stand-replacing fires) did not differ significantly between different stream orientations in this study. Still, the minimum probability (33%) of fire creating a new stand-cohort was on eastern aspects, and the highest probability (46%) was on southern aspects. The likelihood of a fire event creating a new cohort did differ significantly for forest plant association groups with warm, dry shrub/herb and warm mesic shrub/herb having a 51% and 53% chance, respectively, for creating a new cohort and only 36% and 37% probability for the cool, dry grass and hot, dry shrub/grass plant association groups. This study illustrates the importance of fire disturbance in riparian zones as a natural phenomenon, even though fire is likely less frequent than on upland sideslopes. Further, there is variation in fire susceptibility within riparian zones based on physiographic and vegetation factors.

Many studies of reconstructed historical fire regimes in the West have shown that fire suppression and early twentieth-century harvest techniques have changed forest structure and species composition and, in turn, fire susceptibility and severity. For example, Merschel et al. (2014) showed that fire suppression and timber management in eastern Oregon had halved the density of large trees and doubled the density of smaller trees in many forest types compared to pre-European settlement. They also note that the forest type with the most significant departure from the historical structure was in warm-moist environments (mixed conifer) with an increase in small diameter stems. In the northern Sierra Nevada, Van de Water and North (2011) found that riparian areas are more fire-prone, based on the current structure and fuel loads than reconstructed conditions. In the central-eastern Cascade region of Washington, Agee (2003) modeled the historical range of variability (HRV) in forest structure and successional composition based on historical fire return intervals. The model showed an estimated proportion of late-successional forests between 36% - 63% in this region at any given time, much higher than the 12% of late-successional and old-growth proportions found by Camp et al. (1999) in this region during a sampling inventory in 1993. This model assumes that with the cyclical and stochastic nature of fire disturbance, a quasi-equilibrium of forest succession existed at some spatiotemporal scale in this region before Euro-American influence. Further, it should be noted that these models are designed for landscape-level variations that are estimated based on data and observations of upland forests.

Fuel reduction management in riparian zones is a relatively new practice in the West, and the effects on riparian health, development, and function remain unclear (Stone et al., 2010; Dwire et al., 2010). However, many studies show that fire is an essential process in the riparian zones that maintains forest vegetation structural and compositional variability (Messier et al., 2012) and provide pulses of in-stream chemical and structural variation that stimulate aquatic productivity (Malison & Baxter, 2010). For example, Flitcroft et al. (2016) modeled the potential effects of wildfire on Chinook salmon habitat in the Wenatchee River subbasin in central Washington. Specifically, the authors modeled the effects of wildfire on fine sediment input, wood input, and stream temperatures to assess the pre- and postfire habitat quality potential for three Chinook salmon life stages. This study showed the potential of wildfire to increase the quality of habitat for adults and juvenile life stages of the Chinook salmon while decreasing the quality of habitat for the egg and fry life stages. Their investigation also revealed a limited availability of high-quality juvenile life stages pre-fire. These results suggest that fire suppression in these areas may, in some situations, limits quality Chinook habitat for some life stages. While thinning treatments within riparian zones may recover some function (reduced competition, reduced susceptibility to higher severity fires), they may exclude some essential and natural processes suggesting ongoing monitoring of the effects of management on function are important.

## Review of Other Agencies

The following is a brief review of how other public agencies intermingled and adjacent to CMER lands address riparian classification and management. It is presented as helpful background and context on how other management entities approach the classification and management of riparian areas similar to those encountered in ETHEP while recognizing that the agency mandates guiding riparian management differ among agencies and those on CMER lands. National forests are guided by aquatic conservation strategies incorporated in each Forest's Land Management Plan. In comparison, Western states have rules and regulations for riparian timber harvest on non-federal land (state, private, tribal, etc.). Ecological factors, laws, and stakeholder interests can differ considerably. Thus, there is variation in regulations. However, although they vary, the rules generally aim to preserve and restore viable salmonid habitats and maintain water quality in the western states. Because the intent and purpose of these regulations are similar, a review of their approach to riparian areas is also relevant.

### *National Forests*

In federal forest lands of eastern Washington, the USFS classifies and delineates riparian areas based on valley width and gradient separated into four channel types; and vegetation divided into several common dominant covertypes of riparian zones (Kovalchick & Clausnitzer, 2004). The fluvial surfaces that define channel types are described by upland, slope toe, upper terrace, fen, floodplain, streambank, and bar. The different fluvial surfaces and their width variation can affect the processes that drive function. Covertype classifications are separated into the seven most common conifer species, a mixed conifer group that contains less commonly occurring conifer species (mainly subalpine larch, lodgepole pine, and Douglas-fir; Douglas-fir is more common in non-federal forest lands and lower elevation plots), aspen and willows, and a mixed deciduous (mainly alder, birch, maple, and oak). The dominant deciduous covertypes are not considered important timber species but beneficial for riparian health. The dominant conifer covertypes are described by their elevational ranges, life history, and historical disturbance regimes (fire) that help inform their management options. Management options for regeneration, yield, function, and ecosystem services are described in Kovalchick & Clausnitzer (2004) for each delineated riparian covertype on federal land. The approach of the federal delineation system of riparian areas of eastern Washington is like other federal forest land classification systems that focus primarily on dominant covertype but also incorporate geomorphological information. This approach combines attributes from landscape-level (e.g., elevation, valley morphology) and ecosystem-level classification (e.g., vegetation characteristics, fluvial surfaces, soils) to determine the size of the riparian area. Thus, no standard "buffer width" is described in Kovalchick & Clausnitzer (2004). In a synthesis and evaluation of forestland classification methods, Pregitzer et al. (2001) note that while these methods, in conjunction with one another, are effective at understanding current and future habitat conditions, they potentially focus too much on climax communities (or other preferred successional levels) and leave out important information about the structure, understory composition, other potential covertypes, and variation in successional status. The methods used to delineate federal riparian areas are discussed in more detail in the *Framework development* section of the methods.

The application of this riparian classification framework varies among the National Forests intermingled with CMER lands and are prescribed in each Forest's Land Management Plan. Generally, each Forest is tasked with maintaining forest productivity and viable habitat for various important and protected aquatic and terrestrial species. For example, the Okanogan-Wenatchee National Forest Management Plan imposes riparian buffer regulations described in the Northwest Forest Plan Aquatic Conservation Strategy. Under this plan, the variations for buffer width regulations and prescriptions are assessed at a watershed level and are based on preserving and restoring vital ecological processes (e.g., habitat, natural disturbance regimes, etc.). Expected riparian management widths for perennial fish-bearing streams are a minimum of 150 feet for first, second and third order streams with an incremental increases of up to 240 feet for sixth order and greater streams (NWFP-FSEIS, 1994). Buffer widths and prescriptions for the Colville National Forest are described in the 2019 Colville National Forest Plan Programmatic Environmental Impact Statement (CNF-FEIS, 2019). Under this plan, riparian habitat conservation areas (i.e., riparian management areas) of fish-bearing streams have a minimum buffer requirement of 300 feet slope distance from the outer edge of the 100-year floodplain. This buffer width regulation applies to all Colville National Forest fish-bearing streams regardless of the selected plan alternative. The Umatilla National Forest that encompasses the Blue Mountain ecoregion of eastern Washington follows the National Forest Service Forest-Wide Standards and Guidelines best management practices (BMPs) for riparian areas. Under these guidelines, no standard, measurable buffer width is imposed on riparian zones. However, the target prescriptions are designed to preserve desirable functions and characteristics of the riparian areas (LW, vegetation coverage, habitat) that extend various distances from the stream (e.g., maintain 80% cover on fish-bearing streams). The widest buffer prescription requires a 250 distance from bankfull width for soil protection, maintaining < 10% soil exposure.

### *First Nation and Tribal Lands*

Tribal nations of eastern Washington are sovereign governments and, thus, manage forested riparian areas under a different plan than federal and state governments. The two largest governing entities of tribal lands in eastern Washington are the Yakama Nation and the Confederated Tribes of the Colville Reservation. Current riparian management practices for the Yakama reservation are described in the Forest Management Plan: Yakama Reservation developed in 2005. The most current riparian management practices for the Colville reservation are found in the 2015 Forest Management Plan: Colville Indian Reservation. Both forest management plans prescribe riparian buffer widths and management practices on a site-by-site basis.

The Yakama reservation manages 10,403 acres of forested riparian areas. Under this management plan, there are no fixed buffer width prescriptions for riparian areas except for a 20-foot buffer adjacent to all streams where machinery use is prohibited. Beyond the machinery-exclusion zone, the guidelines for riparian management are more nuanced and use an “adaptive modified approach to protection.” Thus, specific buffer width and resulting prescriptions are dependent on site context. Buffer delineation varies for each site based on flood-prone area, area of active channel migration, the extent of riparian and potential riparian vegetation, soil type, adjacent sideslope sensitivity, and extent of potential LW contributing vegetation. Special circumstances such as the presence of important or protected riparian-dependent species (e.g., American beaver) presence, or the potential of old growth stands may further extend the buffer area.

The Colville Indian reservation manages >28,000 acres of forested riparian areas defined by the Colville Forest Practices Act. Under this management plan, riparian areas are removed or deemed ineligible for commercial harvest. No standard buffer width or riparian management area delineation method is described in this plan. Instead, the protection of riparian areas is noted in each best management practice section. For example, under the road maintenance and construction BMPs, any “Streambanks and riparian areas exposed (non-vegetated) by management activities, construction or natural impacts are to be re-vegetated immediately.” For silvicultural prescriptions, the management plan requires a variety of systems that vary from site to site based on local needs and objectives. The only treatments described in this plan that use thresholds for prescription advisement are for leave tree and coarse woody debris retention. Riparian areas are divided into “dry" and “moist” forest types for these prescriptions.

### *Oregon*

Eastern Oregon contains many features and habitats similar to those in eastern Washington, especially along the east Cascade Region and the Blue Mountains. The most current regulations for fish-bearing streams for non-federal lands in Oregon are presented in the Oregon Department of Forestry Rules and Forest Practices Act Chapter 629. These rules were created in response to the 2012 Oregon Board of Forestry decision that previous regulations of riparian buffers were insufficient in protecting desirable fish and aquatic species habitats.

Stream temperature was the primary factor in maintaining these habitats; thus, shade models were used to develop harvest regulations. Groom et al. (2018) derived one of the models used in determining acceptable harvest levels based on their effects on shade reduction and, consequently, stream temperature increases. While the results of this model suggested the most effective method of reducing stream warming required a 27.4 m (90 ft) no-cut-slope-distance buffer width, the regulations implemented have varied, and riparian management area widths are dependent on the size of the stream.

Fish-bearing streams (Type F) have a general, state-wide buffer width prescription regardless of region. Streams are divided into three classes based on average annual flow: small = 2 cubic feet per second or less, medium = greater than 2 and less than 10 cubic feet per second, and large = 10 cubic feet per second. The designated riparian management area (RMA) widths are 50 ft, 70 ft, and 100 ft as measured from the bank full width (BFW) for the small, medium, and large stream flow classes. Stream sizes are defined by average annual flow and must be designated by state foresters. All RMAs contain a no-cut policy for all trees within 20 feet of the BFW, any trees leaning over the channel, and all understory vegetation within 10 ft of the BFW. In addition, all downed wood and snags that are not safety or fire hazards must be retained, and any snags felled to reduce risks must be retained where they are felled.

On February 2, 2022, Oregon forest sector companies, small woodlands associations, and prominent conservation and fishing groups presented a proposal for new prescriptions to the Oregon Legislature and Oregon Board of Forestry. The proposed changes would combine Type F and SBBT streams to have the same prescriptions, extend the no harvest zone to 30 feet, and extend RMA widths from 50 ft, 70 ft, and 100 ft to 75 ft for small and medium and 100 ft for large streams.

### *Idaho*

The Idaho Forest Practices Act imposes the least restrictions on riparian forest harvest relative to Washington, Oregon, and California. Idaho has no standard no-cut-buffer width for streams of any class or order, but landowners are encouraged to leave trees immediately adjacent to streams. The riparian area timber harvest regulations have recently been updated as of March 2022. The change came in response to a before-after control-impact (BACI) experimental analysis of the "old shade rule" implemented in 2014 (Link et al., 2019). Results of this study suggested that the harvest targets of the old shade rule resulted in a shade reduction that was 50% less than expected and thus was an over-regulation of landowners. The Idaho Department of Lands cited this paper as a need to revise the Class I tree retention rule, and the new "Shade Rule" was approved by the Idaho Legislature.

The current shade rule uses a weighted tree count (WTC) based on tree diameters (i.e., larger trees are higher weighted) with varying weights required by region and covertype. The riparian management zone for all fish-bearing (Type 1) streams is 75 ft wide as measured from the high-water mark, and targets are defined for 100 ft reach increments. Idaho is divided into three regions from north to south, and the target weights become lower moving south. The lowest weights are for "drier forest" forests dominated by Douglas-fir and ponderosa pine. Regulation of non-tree vegetation and streamside rocks is not explicitly regulated. It is only required to be left in areas where they provide shade over the stream and stabilize the soil. Large woody debris is to be left in RMZ if longer than the stream width or 20 ft; or sufficiently buried to maintain position during flooding and high-flow events.

### *California*

Current regulations and prescriptions in California were taken from the California Forest Practice Rules 2022. California has the most variation in riparian management prescriptions and the widest no-cut buffer area relative to Washington, Oregon, and Idaho. The riparian buffer's width depends on the slope, proximity to anadromous migration/spawning areas, and potential for flooding. Regulation of timber harvest in management areas adjacent to fish-bearing streams (Class 1) is prescribed by zones (core, inner, outer). The core zone is a 30 ft wide no-cut buffer where all trees are retained for all fish-bearing streams (Class 1). The width and prescriptions of the inner and outer zones vary depending on whether they are located within the coastal anadromous region (western California) and if valley morphology allows for flood-prone areas or is more confined.

Class 1 streams with flood-prone areas or channel migration have a minimum inner zone of 70 ft and a maximum of 120 ft, depending on the size of the flood-prone area. Within the inner zone, canopy cover should not be reduced below 80% if the stream is in the coastal anadromous habitat and 70 % for all other watersheds. A minimum of 13 of the largest trees per acre must also be retained in the inner zone. The outer zone extends another 50 ft from the inner zone, and the canopy cover minimum is 50 % post-harvest. There is no regulation for large tree retention in this zone, but it requires retaining wind-firm trees.

In confined channels, the inner zone is 70 ft in the anadromy zone and 40 ft in all other watersheds. The canopy cover minimum is 70 % for both habitats, and the largest tree retentions are 7 and 13 per acre for the anadromy and non-anadromy watersheds, respectively. The outer zone is 50 ft in the anadromy zone and 30 ft in other watersheds; the canopy cover minimum is 50% for both habitats.

The governing entities described above define, delineate, and manage riparian areas adjacent to fish-bearing streams differently. For example, buffer widths and their prescription targets can vary based on stream size, valley morphology, fluvial process, landscape position, vegetation structure and composition, or a combination of these factors. This variation in delineation and regulation illustrates the variation in the priorities of desirable functions and the physiography and vegetation of forested, western riparian areas. Thus, the delineation of riparian areas is context-dependent.

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