<u>Project Number: EMC-2017-WWW</u>

Project Name: Effectiveness of Class II watercourse and lake protection zone (WLPZ) Forest Practice Rules (FPRs) at maintaining or restoring canopy closure, stream water temperature, and primary productivity.

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Synopsis: The following document is a proposal to provide a preliminary investigation of the effectiveness of watercourse and lake protection zones (WLPZ) at maintaining or restoring key riparian and aquatic functions in classified watercourses. Riparian forests provide critical functions to adjacent streams, including shade that moderates stream temperatures, a cooler, more humid microclimate, bank and channel stability, large wood recruitment, and a source of organic matter. However, concerns about riparian forest management continue despite substantial efforts to mitigate impacts with WLPZ Forest Practice Rules (FPRs) (Young, 2000; Czarnomski *et al.*, 2013). As such, an evaluation of the effectivess of WLPZ regulations is critical to assessing the overall effectiveness of the California FPRs at protecting the beneficial uses of water and functions of riparian zones.

1. Background and Rationale

Estimating the thermal response of headwater streams and rivers to forest managmenet activities is increasingly important given current and projected climate change (Luce *et al.*, 2014; Pyne and Poff, 2017) and increasing land use activities (Hester and Doyle, 2011). Historical forest management activities, such as harvesting near streams, often resulted in increased summertime stream temperatures because of reduced shade and increased solar radiation reaching the stream surface (Moore *et al.*, 2005a; Studinski *et al.*, 2012). Changes in stream temperature regimes are principally a concern when resulting temperatures are outside the range of thermal tolerances for aquatic ecosystem biota (Dunham *et al.*, 2003; Bear *et al.*, 2007). Elevated stream temperatures can affect primary productivity (D'Angelo *et al.*, 1997; Morin *et al.*, 1999), benthic invertebrates (Hogg and Williams, 1996; Hawkins *et al.*, 1997; Caruso, 2002), fish habitat (Eaton and Scheller, 1996; Beitinger *et al.*, 2000; Waite and Carpenter, 2000; Ice, 2008), as well as the rates of in-stream chemical processes (Demars *et al.*, 2011).

To address and mitigate negative impacts from forest harvesting activities in and around riparian zones, best management practices (BMPs) have been developed and implemented (Cristan *et al.*, 2016). In particular, BMPs aimed at maintenance or reestablishment of streamside forests have been effective at improving many of the functions of riparian zones. For example, there is strong evidence that riparian forests have been effective at providing shade, limiting direct solar radiation to the stream, and mitigating changes in stream temperature after contemporary forest harvesting (Bladon *et al.*, 2016). In theory, maintenance of shade should be an effective strategy to mitigate stream temperature changes following forest harvesting as direct solar radiation and atmospheric conditions are often the primary driver for summer stream temperatures (Sinokrot and Stefan, 1993; Johnson, 2004). There is recent evidence, though, that too much shade from riparian forests may reduce in-stream photosynthesis (primary productivity) with associated declines in aquatic insects and fish productivity (Newton and Ice, 2016). Additionally, there is some evidence that other factors, such as stream orientation (Gomi *et al.*, 2006), steepness of channel slopes (Kasahara and Wondzell, 2003), and the contributions to streamflow from groundwater or hyporheic exchange (Moore and Wondzell, 2005) could all influence the effectiveness of riparian zones. However, the relative importance of these different factors and the possible tradeoffs in riparian function haven't been adequately or holistically examined.

In California, the Forest Practice Rules (FPRs) outline the regulations for operations within the Watercourse Lake and Protection Zone (WLPZ), the strips of retained trees and/or vegetation, along both sides of a watercourse (Figure 1). Regulations are designed to ensure that "timber operations do not potentially cause significant adverse site-specific and cumulative impacts to the beneficial uses of water, native aquatic and riparian-associated species, and the beneficial functions of riparian zones" (The California Department of Forestry and Fire Protection, 2017). As such, the FPRs for the WLPZ have the potential to contribute toward the objectives of key policies, such as the Endangered and Threatened Species Policy, Salmon Policy, Water Policy, and Joint Pacific Salmon and Anadromous Trout Policies (The California Department of Forestry and Fire Protection, 2017). However, again, the effectiveness of current WLPZ regulations have not been thoroughly examined.

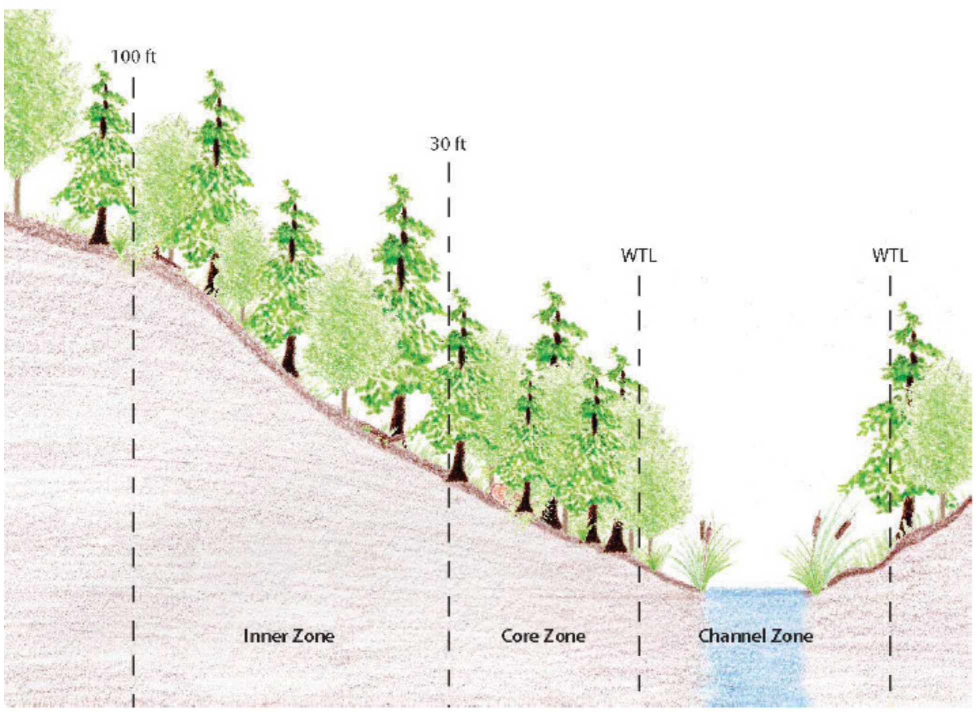

Figure 1. Example of the width requirements for the inner zone and core zone of the WLPZ in Class II-L streams in the Coastal Anadromy Zone of California (State of California, 2017).

The effectiveness of current WLPZ regulations at mitigating adverse site-specific and cumulative impacts are particularly important in Class II-L (Large) watercourses. In California, the Forest Practice Rules (FPRs) afford the most protection to Class I (fish bearing) relative to

Class II (aquatic life other than fish) and Class III streams (not supporting aquatic life). However, it has been recognized that headwater systems can be critically important to the water quality in downstream sites (MacDonald and Coe, 2007). This has led to the establishment of stricter provisions for Class II Large (Class II-L) watercourses compared to other Class II streams, according to the "Andromous Salmonid Protection Rules, 2009", and modified by the "Class II-L Identification and Protection Amendments, 2013" rule package approved by the State Board of Forestry and Fire Protection in October, 2013. At present, the regulations require a 30 foot core zone and a 70 foot inner zone within watersheds of the coastal anadromy zone (Table 1). One of the objectives of these rules is to protect anadromous salmonid habitat by minimizing potential increases in temperature, sediment, and nutrients from Class II and Class III watercourses draining into Class I systems.

Table 1. Core zone and inner zone width requirements for WLPZ associated with Class II-S and Class II-L streams within and outside of the coastal anadromy zone (State of California, 2017).

Water Class	**Class II-S (feet)**				**Class II-L (feet)**			
Geographic location	**Watersheds in the coastal anadromy zone**		**Watersheds outside the coastal anadromy zone**		**Watersheds in the coastal anadromy zone**		**Watersheds outside the coastal anadromy zone**	
Slope class	Core Zone (feet)	Inner Zone (feet)	Core Zone (feet)	Inner Zone (feet)	Core Zone (feet)	Inner Zone (feet)	Core Zone (feet)	Inner Zone (feet)
≤30%	15	35	10	40	30	70	20	80
30-50%	15	60	10	65	30	70	20	80
>50%	15	85	10	90	30	70	20	80

2. Objectives

The broad objectives of the proposed research are to begin to address the following critical questions associated with the high priority thematic area (EMC Strategic Plan Theme 1-WLPZ Riparian Function (Effectiveness Monitoring Committee, 2017)) related to watercourse and lake protection zones (WLPZ) of Class II-L watercourses in the Coast District[1]:

a) Are the current FPRs effective at maintaining and restoring WLPZ canopy closure?
b) Are the current FPRs effective at maintaining and restoring stream water temperature?
c) Are the current FPRs effective at maintaining or restoring primary productivity?
d) What stream and riparian forest characteristics are important for determining effectiveness of the WLPZ?

[1] See 14 CCR § 916.9 [936.9,956.9] (c) (4).

To fulfill the objectives of this study will require several, overlapping phases. Here we provide specific details regarding Phase I, including details about how the knowledge generated during this phase will contribute to future phases to fulfill the broader objectives mentioned above.

Core questions we will address in Phase I (this proposal), which will contribute to the broad, long-term objectives are:

a) How does shade provided by the WLPZ to Class II-L streams vary across different intensities of forest harvesting?
b) How does stream water temperature in Class II-L streams vary across different intensities of forest harvesting?
c) How does primary productivity in Class II-L streams vary across different intensities of forest harvesting?

3. Approach

This study will provide data and analysis for Phase I of a multi-phase project to address questions related to the high priority thematic area of watercourse and lake protection zones (WLPZ) of Class II-L watercourses in the Coastal Anadromy Zone (Figure 1).

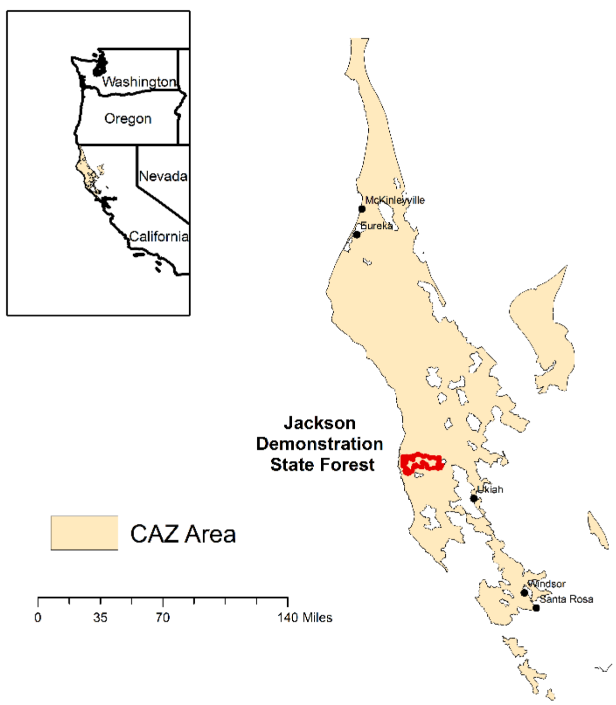

Figure 1: Map of the Coastal Anadromy Zone in western California, which will be the focus region for the proposed study. A detailed field campaign will be developed in the Jackson Demonstration State Forest at Caspar Creek, while an additional campaign will occur across the region in collaboration with LTOs.

One component of Phase I will take advantage of the infrastructure available at the large, paired-watershed experiment, the Caspar Creek Experimental Watershed Study. Six research watersheds are currently (summer/fall 2018) being harvested at different intensities. We will collect data from four watersheds with varying harvesting intensities (basal area reductions) (Table 1). Watersheds were selected based on similarities in size, aspect, and range of basal area reductions to facilitate comparisons. This type of larger, nested-watershed study allows us to evaluate whether local practices are effective and/or have downstream effects.

Table 1. Sub-watersheds in the Caspar Creek Experimental Watershed Study that will be included in the proposed research.

Watershed Name	Watershed ID	Harvest Intensity	Basal Area Reduction Rate (%)
Williams	WIL	None	0%
Treat	TRE	Low	35%
Uqlidisi	UQL	Moderate	55%
Ziemer	ZIE	High	75%

We propose to collaborate with private forest landowners in the CAZ zone in California to instrument multiple Class II-L stream reaches within six additional watersheds, which may be scheduled for harvest in ~2-3 years. We will collect the same data as we collect at Caspar Creek. These sites may serve as additional control for comparison with the harvested sites at Caspar. However, the data collected with also serve as baseline, pre-treatment data for Phase II of this research. Phase II will be based on a robust before-after, control-impact study design to test the effectiveness of the WLPZ on industrial forest land. Morover, the proposed reach-scale studies across multiple watersheds are appropriate to provide data that will help understand the variability of WLPZ effectiveness across the broader CAZ.

3.1. WLPZ Stand structure

We will collect data on WLPZ stand structure from ~8-10 fixed area plots in each watershed (~80-100 plots total). Fixed area plots will be approximately 1/10 acre (~400 m^2). Data will be collected on all standing live and dead trees with diameters ≥ 4 inches (>10 cm) at breast height [4.5 ft (1.37 m) above ground] that are within the WLPZ. We will record the following data for each tree: condition (live or dead), species, diameter at breast height (DBH), distance and azimuth from plot center. The canopy class (overstory, understory, or open) will be recorded for all live trees. Data recorded for dead trees includes decay class and mortality agent (e.g. wind, erosion, suppression, fire, insects, disease, and physical damage) when it is possible to determine. This foundational data is necessary to determine characteristics of the WLPZ likely to control its effectiveness and to interprate other data from this study.

3.2. WLPZ canopy closure

We will use hemispherical photography to quantify canopy closure and assess effectiveness of the WLPZ at influencing solar radiation transmission to the stream. Hemispherical photographs will be taken over the center of the stream along all reaches in the study to adequately characterize the entire WLPZ in all watersheds (~8-10 per watershed; ~80-100 total). All photographs will be taken vertically up into the canopy from directly over the stream with a Nikon D7100 equipped with a Sigma 45mm f2.8 circular fisheye lens. Photographs will be taken following the recommended standard protocols for exposure, leveling, and image processing (Beckschäfer *et al.*, 2013; Glatthorn and Beckschäfer, 2014; Origo *et al.*, 2017). The resulting photographs record the sky visible through gaps in the forest canopy, as well as the structure of the canopy (e.g., LAI). We will use these features of the photographs to estimate solar radiation transmitted through (or intercepted by) the WLPZ, which would then be received at the stream surface (Gonsamo *et al.*, 2011).

Figure 2. Hemispherical photography for estimates of canopy closure.

3.3. Stream temperature measurements

Within each watershed (4 at Caspar, 6 on private land) we will measure stream temperature (T_s) using thermistors (Onset TidbiT v2 Water Temperature Data Logger) programmed to collect data at 30-minute intervals. We will pair stream temperature (T_s) loggers with air temperature (T_a) data loggers to develop direct, local relationships between T_s and T_a. Loggers will be placed approximately 100 m apart along the thalweg of each stream (~8-12 loggers per stream) (Figure 3). Sensors will ideally be located within riffle sections of the streams—we will avoid stagnant pools.

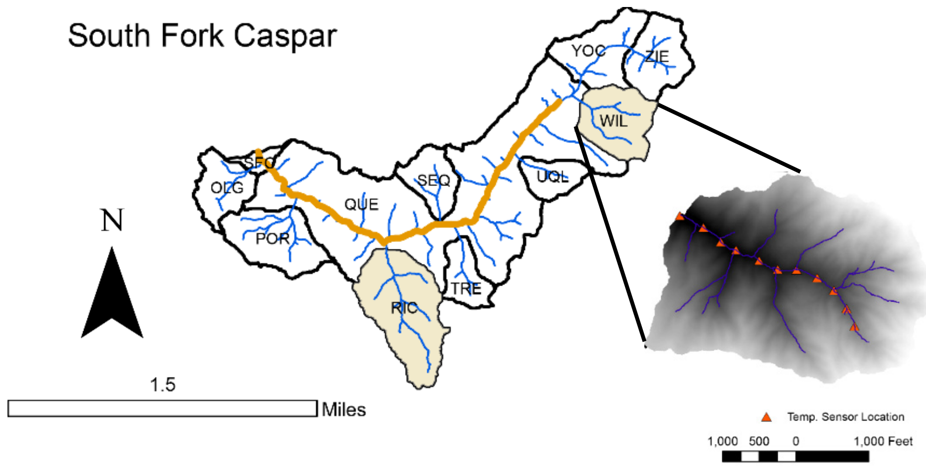

Figure 3: Map of the sub-waterhseds of South Fork Caspar Creek, which will be the focus for a component of the proposed study. The inset shows an example of stream temperature sensor locations within the watersheds, which will be paired with air temperature measurements and measurements of WLPZ structure and function.

3.4. Primary productivity

Stream periphyton is a critical component of aquatic ecosystems, providing food for invertebrates, thus supporting fish. However, periphyton growth may be light-limited or influenced by temperature (Morin *et al.*, 1999; Kiffney and Bull, 2000). As such, measurements of this parameter are critical to understanding tradeoffs associated with WLPZ retention. To quantify summer stream periphyton, we will measure benthic algal biomass with a BenthoTorch (BBE Moldaenke; http://www.bbe-moldaenke.de) at each of the stream temperature locations. The Benthotorch (Figure 4) is a hand-held, fluorimeter that estimates in situ chlorophyll-*a* (chl-*a*) concentrations from the stream substrate based on absorbance of fluorescent light (Kahlert and McKie, 2014). Chl-*a* is the dominant photosynthetic pigment of benthic algae in streams, so provides an approximate estimate of primary productivity (Gregory, 1980). We will collect measurements at five (5) replicate locations randomly selected around each stream temperature sensor (~400-500 total).

Figure 4. BenthoTorch fluoromiter for *in situ* estimates of primary productivity.

Field measurements will be compared against the standard brush sampling/ethanol extraction/spectrophotometric analysis method to assess the accuracy of field measurements (Marker *et al.*, 1980; Nusch, 1980). Locations near the BenthoTorch sites will be selected randomly; sample rocks will be covered with a cap of similar diameter to the measurement surface of the BenthoTorch (3 cm vs 1 cm for the cap and BenthoTorch respectively). The cap will remain in place while the remainder of the rock will be scrubbed with a nylon brush and rinsed. Following the rinsing procedure, the cap will be removed and the area below will be scrubbed vigorously with a nylon brush. This procedure will be repeated two additional times to collected a composite sample. The removed material from the small diameter sampling surface will be placed into a 250 mL bottle and topped off to 250 mL with stream water. The samples will be kept cold prior to transport to the laboratory. In the laboratory, the samples will be filtered in the dark (0.7 µm glass fiber filters). Filters will be stored in centrifuge tubes at -20°C for 18 days prior to extraction using sonication and hot 95% ethanol. Chl-*a* concentrations of the extractant will measured using a spectrophotometer and not corrected for phaeophytin as the BenthoTorch cannot distinguish between photoactive pigments.

3.5. Stable isotope pilot

We will collect stream water samples for stable isotope analysis from ~4–6 sites every 2 weeks (~26 samples per site each year) through the course of the study. Samples will be collected and stored in air-tight vials to ensure there is no evaporation prior to lab analysis. All samples will be analysed for dual isotopes (δ^2H, $\delta^{18}O$). Precipitation samples are currently being collected in an evaporation free sampler at Caspar Creek as part of another study. We will add a similar evaporation free precipitation collector in the privately-owned watersheds. These input (precipitation) and output (streamflow) water stable isotope data will be used to estimate water transit time and the variability in the summer rainfall runoff generation process. This information is critical to undersand variable temperature response in sites with similar canopy closure or WLPS structure and relevant for interpreting WLPZ effectiveness at influencing summer stream temperature. We will be able to identify sites with substantial groundwater contributions and hyporheic exchange that can potentially buffer stream temperature patterns by decreasing a stream's sensitivity to energy inputs (Moore *et al.*, 2005a; Moore *et al.*, 2005b). Stable isotope data will provide process based insight into which streams are more/less likely to be responsive to changes in energy inputs following forest harvesting.

4. Potential future phases

In Phase II of the proposed research some potential studies include:

- Completion of the BACI study in watersheds instrumeneted on private land as part of this study. We would continue to collect and analyse stream temperature, primary productivity, and water stable isotope data from the sites on private land after forest harvesting. This will provide a robust data set to assess the effectiveness of WLPZ on industrial forest land under current Forest Practices Rules.

- Formulation of a deterministic net radiation model that simulates radiative fluxes through the WLPZ. We would develop a model to assess which riparian forest and catchment characteristics are important for determining effectiveness of the WLPZ. Data from the hemispherical images both before and after harvest will be used to parameterize the model. This will be combined with stream temperature data to assess the effects of different WLPZ structural characteristics and catchment characteristics (e.g., channel orientation, discharge, groundwater) on stream temperature.
- Assessment of the linkage(s) between WLPZ structure and function on stream temperature, primary productivity, and fish. This component of Phase II would involve a collaboration with D. Warren (OSU; or similar) to more directly investigate the effectiveness of the WLPZ at maintaining fish habitat.

5. Proposal collaborators

We will collaborate with Joseph Wagenbrenner (Research Hydrologist) and Elizabeth Keppeler (Hydrologist) from the USFS Pacific Southwest Research Station. We will also collaborate with Drew Coe and Pete Cafferata from CAL FIRE, who will aid in site selection and development of relationships with private landowners in California. We will need to collaborate with private landowners to achieve the core objectives of the proposed research.

6. Timeline

The duration of the project will be 2.25 years starting June 1, 2018 and continuing until August 31, 2020 (Table 1). The timeline presented in Table 1 indicates the core activities associated with each of the main data collection components of the research.

Table 2. Project timeline.

Activity	Year 1				Year 2				
	Su18	Fa18	Wi19	Sp19	Su19	Fa19	Wi20	Sp20	Su20
Site selection	■								
Instrumentation of field sites at Caspar Creek	■								
Instrumentation of field sites on LTO land	■								
Mensuration data on WLPZ stand structure		■	■	■					
Hemispherical photos for canopy closure				■	■				
Field data collection of primary productivity				■	■				
Laboratory analysis of algal samples						■	■		
Temperature data collection	■	■	■	■	■	■	■	■	
Water samples collected for isotope analysis	■	■	■	■	■	■	■	■	
Laboratory analysis of water samples for isotopes		■	■	■	■	■	■	■	
Data analysis					■	■	■	■	■
Presentation of results at international conference							■		
Thesis defense								■	
Peer reviewed manuscripts submitted									■
Foundational work for Phase II					■	■	■	■	■

7. Budget justification

A. **Salaries**: A total of $93,478 is allotted for salaries for PI Bladon ($9,614), co-PI Segura ($9,638), an FRA Alleau ($5,648) to complete the laboratory analyses, a M.S. student to ($41,244), and a summer field assistant ($15,600).

B. **Fringe benefits**: A total of $30,224 was calculated for fringe benefits for all personnel for the duration of the project, and follow approved guidelines. Fringe benefits for FRA Alleau is 63%. Fringe benefits for the PI and Co-PI were calculated at a rate of 48% and 49%, for years 1 and 2, respectively. The M.S. student fringe benefits are 29% and 31% for years 1 and 2, respectively. Fringe for the hourly hired field assistant is 8% every year.

C. **Travel**: A total of $33,777 is requested for travel for the project duration. This includes:
   - Field work, year 1: $14,027
   - Field work, year 2: $14,027
   - Post-doctoral scholar and PI attendance and presentation of research findings at the American Geophysical Union Annual Fall Meeting: $5,723

D. **Materials and Supplies**: A total of $23,949 is requested for instrumentation and materials to measure stream water, air temperature, canopy closure, WLPZ structure, and primary productivity.

E. **Publication Costs:** A total of $1,000 is requested to cover the publication cost of one manuscript.

F. **Computer Services**: A total of $600 per year is requested to cover the cost of storage of geospatial data.

G. **Tuition**: N/A.

H. **Total direct costs:** Total direct costs of this project are $224,177.

I. **Indirect costs:** Total indirect costs of this project are $22,544.

J. **Total direct and indirect costs:** Total project costs are $246,721.

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