EMC-2015-001

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Title: Multiscale investigation of perennial flow and thermal influence of headwater streams into fish bearing systems

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1. Introduction

The impacts of timber harvesting and other land uses on water quality have been an environmental concern for many years. One of the primary concerns is the potential for land use activities to produce increases in stream temperature during the summer and increases in suspended sediment yields during the wet season (Macdonald *et al.*, 2003; Gomi *et al.*, 2005; Moore *et al.*, 2005; Croke and Hairsine, 2006; Gomi *et al.*, 2006; Gravelle and Link, 2007). Water temperature and sediment are the two primary water quality constituents that have been recognized as the dominant causes of impairment in streams in Northern California and throughout the Pacific Northwest (ODEQ, 2004; Hanak *et al.*, 2011). Temperature, in particular, is of special concern in fish bearing streams, especially where threatened and/or endangered aquatic fish species are present. 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 led to the establishment of provisions for Class II Large (Class II-L) water~~-~~courses 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. One of the ~~The~~ objectives of these rules is ~~are~~ to protect anadromous salmonid habitat by minimizing potential increases in temperature, sediment, and nutrients~~, and large wood~~ from Class II and Class III watercourses ~~streams~~ draining into Class I systems. This amendment included an improved ~~classification system~~ method to identify Class II-L ~~systems~~watercourses based on drainage area and active channel width. A Class II-L watercourse is defined as a Class II watercourse that has either of the following characteristics:

- contributing drainage area of ≥ 100 acres in the Coast Forest District, or ≥ 150 acres for the Northern and Southern Forest Districts
- an average active channel width of 5 feet or greater near the confluence with the receiving Class I watercourse.

Given that the above method for determination will sunset on January 1, 2019 pending further evaluation (as specified in the amended FPRs), there is an urgent need to assess the efficacy of the rule.

Aside from the practical challenges associated with defining Class II-L systems, there are also scientific questions related to both the variability in the geographic extent of Class II-L systems and the assessment of their actual impacts on Class I systems. Indeed, the potential ~~impacts~~ influence that Class II-L watercourses can impose downstream will likely depend on the hydrologic regime of the system, which is a function of physiographic and climatic variables, as well as its hydrologic connection to downstream reaches. Therefore, in this proposal we assume that for Class II-L systems to potentially impact downstream reaches they must be perennial (i.e., hydrologically connected) during the time period of the potential negative effect. In the case of stream temperature, streams must be hydrologically connected during the summer period (i.e., perennial). Therefore, understanding the spatial and temporal variability of the perennial extent of streams is central to the rationale of this proposal.

The upper extent of perennial flow generally varies across the landscape as a function of natural landscape characteristics, climatic regimes, and land use impacts (Montgomery and Dietrich, 1989; Prosser and Abernethy, 1996; Tucker and Bras, 1998; Jaeger *et al.*, 2007; Costigan *et al.*, 2016). For instance, lithology appears to control source area size of forested streams in Washington underlined by basalt and sandstone (Jaeger *et al.*, 2007). However, this study also reported that in both lithologies the location of the channel heads and perennial flow coincided. Channel heads can be defined morphologically as "the upslope limit of erosion and centration of flow within steepened banks" (Montgomery and Dietrich, 1989). While field campaigns to map channel heads are time consuming and expensive, spatial analysis including digital elevation terrain derived methods offer an alternative (Fritz *et al.*, 2008). The early DEM methods were based on a contributing area threshold or on a slope-area scaling relationship (Montgomery and Dietrich, 1989; Tarboton *et al.*, 1991). More recently, LiDAR information has been used in more refined and accurate schemes (Passalacqua *et al.*, 2010; Clubb *et al.*, 2014). However, not all regions have LiDAR data available. Therefore, comparative studies of the effects of improved DEM resolution over a range of environmental conditions could improve understanding of the limits of the different schemes at identifying channel heads and perennial flow. Initial research~~,~~ indicates that the discrepancy between the outcomes from different data resolution increases with terrain steepness (Grieve *et al.*, 2016). Additionally, it is critical to characterize the hydrologic regime (e.g., ~~perrenniel~~ perennial vs. ephemeral) of a stream, as this can influence the accurate identification of channel heads and, therefore, the efficiency of terrain analysis (Wang and Wu, 2013; Costigan *et al.*, 2016).

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From the perspective of this investigation, the perennial extent of a stream is a primary control on the transmission of thermal inputs downstream as cumulative effects (Beschta and Taylor, 1988; Gregory *et al.*, 1991). If a headwater stream warms, this impact is only relevant to downstream reaches as long as they are hydrologically connected. Given the importance of stream temperature as a water quality parameter, there have been many studies regarding changes in the thermal regimes of streams following forest management activities (Macdonald *et al.*, 2003; Moore *et al.*, 2005; Kibler *et al.*, 2013; Guenther *et al.*, 2014; Bladon *et al.*, 2016). Additionally, there is also concern about the downstream transmission of heated water, which would increase the spatial extent of thermal effects on aquatic ecosystems (Moore *et al.*, 2005). This concern has been reinforced by observations of heat inputs being transmitted downstream as cumulative effects (Beschta and Taylor, 1988; Gregory *et al.*, 1991). As such, asymptotic warming is often the supported conceptual paradigm for longitudinal stream temperature patterns (Caissie, 2006). However, the general model of downstream warming likely oversimplifies stream temperature dynamics (Dent *et al.*, 2008; Leach and Moore, 2011). Studies from Oregon, California, British Columbia, and elsewhere have also demonstrated both natural stream cooling in a downstream direction (Madej *et al.*, 2006; Fullerton *et al.*, 2015), as well as cooling of warmed water flowing out of a clearcut and back into a closed-canopy section (McGurk, 1989; Keith *et al.*, 1998; Story *et al.*, 2003). In the context of timber harvesting, recent research from

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across 10 sites in Oregon showed that lithology can be a dominant control on the dowstreamn effect in terms of not only sediment (Bywater-Reyes *et al.* *in press*) but a~~s~~lso temperature (unpublished data). However, while there is growing appreciation for the high degree of variability in longitudinal stream temperature dynamics (Ebersole *et al.*, 2003; Davis *et al.*, 2015; Fullerton *et al.*, 2015, Louen 2016), it is increasingly important to evaluate the influence of local and regional drivers on downstream thermal regimes to improve our ability to predict disturbance responses. This is particularly critical for streams in California given its geologic and geomorphological complexity, as well as its warmer climate regime compared to that in the PNW.

2. Objectives

The objectives of the proposed research are to:

a) Investigate the variability of the relationship between drainage area, active channel width, and perennial flow extent across the Anadromous Salmonid Protection (ASP) area (Fig. 1);
b) Compare the relationships derived in (a) to the rule criteria for Class II-L identification ~~system~~ in terms of both drainage area and average active channel width; determine if these criteria are effective in identying Class II-L watercourses in different lithologies, or if rule modifications are needed;
c) Conduct a pilot study to investigate the downstream propagation of water temperature from Class II-L systems in sites with contrasting lithology, determining if the current FPRs are effective in identifying watercourses that have the potential to translate thermal impacts to Class I watercourses.

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To achieve the objectives we propose to integrate spatial analysis, field observations and mapping, and coupled measurements of stream and air temperature in a two level multiscale approach at the regional and catchment scales. We will utilize available geospatial information including digital elevation terrain models, LiDAR, and geology and hydrometric data to stratify a regional field campaign representative of the ASP region (Fig. 1). In addition, we plan a process driven investigation of the longitudinal variability of the relation between air and stream temperature considering 2 sites representative of the geologic variability of the region.

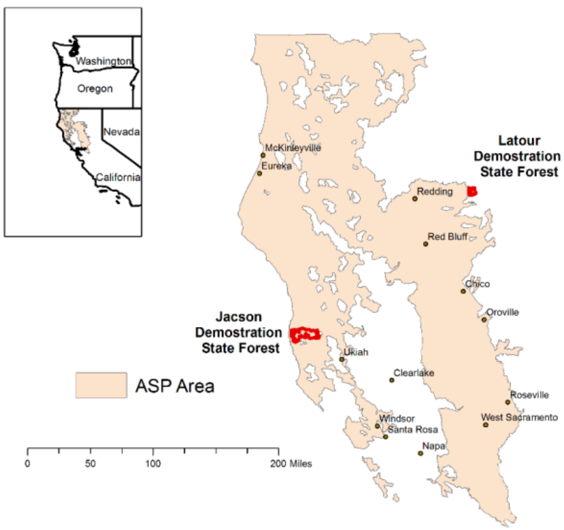

Figure 1: Study area corresponding to the Anadromous Salmonid Protection (ASP). A detailed field campaign will be developed in two ~~State~~ Demonstration State Forests (Jackson and Latour).

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3. Approach

~~Again, t~~This investigation will incorporate two scales of inquiry, including~~:~~ a) broad scale analysis of relative controls of physiographic and climatic variables on the perennial flow extent of Class II-L streams as part of the ASP area, and b) a focused field~~-~~based analysis of the thermal influence of Class II-L on Class I systems incorporating sites underlain by sedimentary and volcanic geology.

3.1. Broad Scale Analysis

We will conduct a stratified field campaign across the confirmed Anadromous Salmonid Protection (ASP) area (Fig. 1). This area is roughly 39,670 sq-miles and encompasses contrasting geology varying from sandstone, shale, and minor conglomerate in the ~~coastal belt~~Coast Ranges to metamorphic and volcanic rocks in the Klamath ~~Basin~~Mountains, and volcanic rocks in the Cascade~~s~~ Range (Fig. 2). We will select a minimum of 100 Class II-L streams across the main geologic units. The site selection will take advantage of available LiDAR (Fig. 2) and hydrometric data. For each site we will conduct a physiographic analysis, including calculation of drainage area, catchment slope, and channel profile. In addition, we will identify the topographic channel head according to available techniques (Passalacqua *et al.*, 2010; Clubb *et al.*, 2014) and utilizing available bare ground topography data. At least half of

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the sites will be visited during the summer to assess geomorphic characteristics including average active channel width and channel slope and to map the perennial extent. In addition, we will analyze available hydrometric data to characterize the hydrologic regime in terms of flow duration curves, recession curve analysis, and hydrologic storage (Sayama *et al.*, 2011). This information will be used to formulate a model of channel head initiation and the extent of Class II-L streams across the region. This analysis will contribute to the formulation of an updated regionalized parameterization of a Class II-L identification system.

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Commented [CD9]: I think the most substantive comment we received from committee was to prioritize the field sampling component over the geospatial analysis. I'm aware this might change the budget, but we might be able to supplement some of the field work with some of our watershed staff.

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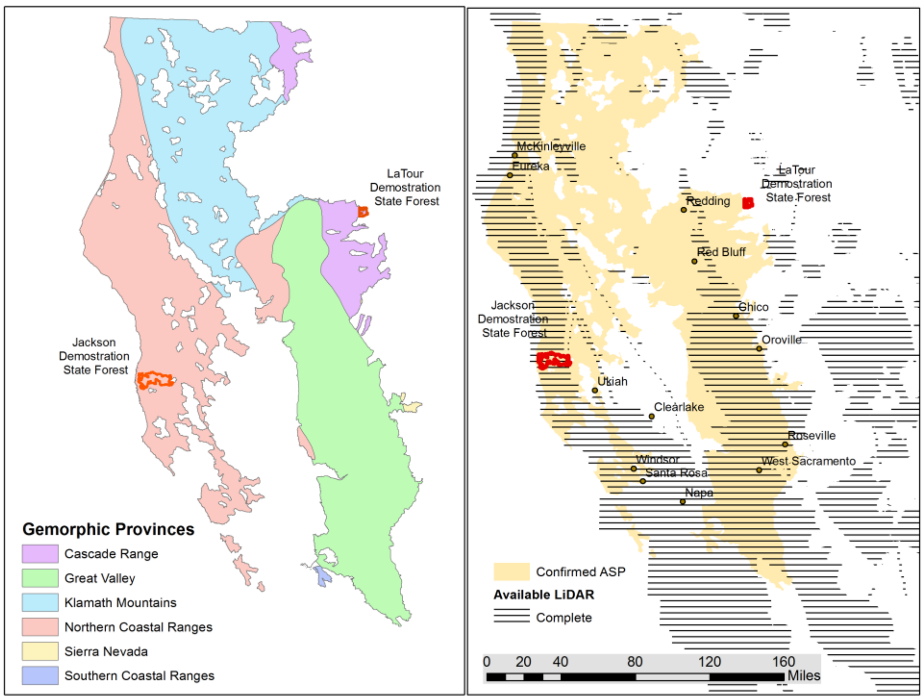

Figure 2: A map of the geomorphic provinces in the study area (left) and available LiDAR (right).

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3.2. Longitudinal trends in stream temperature

We propose a pilot study to investigate ~~the downstream transmission of heated water from upstream to downstream reaches~~longitidunal temperature patterns in catchments draining contrasting lithology, with ~~the~~ Jackson Demonstration State Forest primarily underlain by sedimentary deposits and ~~the~~ LaT~~t~~our Demonstration State Forest underlain by volcanic rocks. We have tentatively selected sites in Jackson and LaT~~t~~our Demonstration State Forests (Fig. 2) because they provide readily available access for research, drain contrasting geology, include sites that have not been recently (<15 yrs) harvested, and have available baseline data that will

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facilitate a robust analysis of trends. We will instrument 3-5 catchments, including sites in Caspar (Fig. 3) and South Cow Creeks. In each catchment we will deploy Onset TidbiT water temperature data loggers to collect stream temperature data (30-minute intervals). Stream temperature (T_s) loggers will be paired 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. The sensors will not only provide information about temperature dynamics over time but also have the potential to facilitate determination of the temporal variability of the perennial extent of the network.

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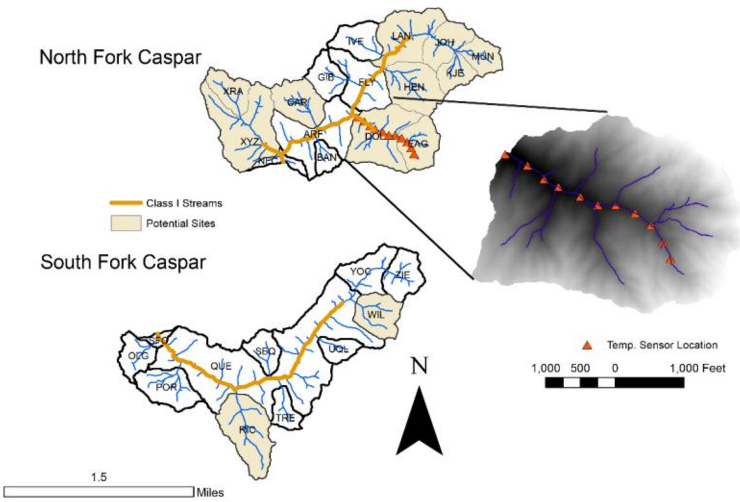

Figure 3. An example of potential sites for thermistors along Caspar Creek in the Jackson Demonstration State Forest.

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The comparison between sites in Jackson and LaT~~t~~our will provide baseline information about heat transmission in the absence of harvesting activities and enable the isolation of the controlling effects of lithology on surface water-ground water interactions. This information will be useful for future studies that target prescription effectiveness, which are beyond the scope of this project but could be part of a second phase.

4. Proposal collaborators

We will collaborate closely with Joseph Wagenbrenner, Research Hydrologist, and Elizabeth Keppeler, Hydrologist, USFS Pacific Southwest Research Station, ~~and~~ representatives for the Caspar Creek Experimental Watersheds. We will leverage existing temperature sensors in Caspar Creek to avoid duplicating measurements. We will also collaborate with Drew Coe and Pete~~r~~ Cafferata from CAL ~~al~~FIRE, who will aid in site selection and data ~~adquisition~~aquisition.

5. Timeline

The duration of the project will be 2 ¼ years starting in the summer of 2017 and extending until December 2019 (Table 1). The timeline presented in Table 1 indicates the core activities associated with each of the objectives presented in section 2 (a-c).

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[Water Board staff noted that they are concerned whether there may be individual watercourses that do not meet that Class II large criteria, but may have sufficient summertime flow as to convey thermal impacts downstream, or support beneficial uses within the Class II watercourse itself, and as such, should be provided Class II large protection measures. It may be beneficial to have some verbiage stating that while this is a valid issue, it is beyond the scope of this study]

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Table 1: Time line of the project.

Activity	Academic Year 2017-2018				Academic Year 2018-2019				
	su17	fa17	wi18	sp18	su18	fa18	wi19	sp19	su19
Objective a-b									
Geospatial data compilation									
Hydrometric data compilation									
Site selection									
Field work									
Data analysis									
Objective c									
Site selection									
Instrumentation									
Temperature data collection									
Data analysis									
Thesis defense									
Logger retrieval									

6. Budget justification

A. **Salaries**: A total of **$81,271** is allotted for salaries for PI, Segura ($9,638), co-PI, Bladon ($9,614), a Masters Student ($51,938), and a field assistant ($10,080).

B. **Fringe benefits**: A total of **$25,139** was calculated for fringe benefits for all personnel for the duration of the project, and follow approved guidelines. Fringe benefits were calculated at a rate of 44% and 45% for the PI and co-PI, for years 1 and 2, respectively. The MS student fringe benefits are 29%, 31%, and 33% for years 1, 2 and 3, respectively. Fringe for the hourly hired field assistant is 8.31% every year.

C. **Travel**: A total of $27,886 is requested for travel for the project duration. This includes:
   - Field work 1st year (objective c): $6,964
   - Field work 2nd year (objectives a and b): $16,894
   - Travel cost associated to the student participation at the American Geophysical Union Annual Fall Meeting: $ 1,618
   - Field work 2nd year (objective c): $2,520

D. **Materials and Supplies**: A total of $20,550 is requested for a suite of instrumentation and materials to measure water and air temperature.

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**: The total requested funding for graduate student tuition is $34,748 for the 2¼ years duration of the project.

H. **Total direct costs:** Total direct costs of this project are $191,904

I. **Indirect costs:** Total indirect costs of this project are $18,859.

J. **Total direct and indirect costs:** Total project costs are $210,763.

Note: The travel and instrumentation costs associated to objective c is ~$30,000. If this objective was eliminated the total budget would decrease to ~$180,000.

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