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Informing changes to riparian forestry rules with a Bayesian hierarchical model

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ABSTRACT

In 2012 the Oregon Board of Forestry (Board) determined that current forestry rules were insufficient at preventing the degradation of cold water in salmonid-bearing streams. Consequently, the Oregon Department of Forestry required a means for evaluating and comparing the effectiveness of newly-proposed harvest scenarios. We derived a field-data based method for simulating riparian harvest and modeling the resulting effects on stream temperature that could be used for evaluating different harvest scenarios. We simulated prescribed harvests by using previously-collected riparian stand data. To create a predictive model, we modified and joined two earlier stream temperature and shade models from Groom et al. (2011b) into a Bayesian hierarchical model. The predictive model produced parameter estimates and temperature change metrics that aligned with the previous findings. The model predicted that harvest according to a full implementation of the State forest harvest plan would on average result in a 0.19 °C increase, while the model predicted that a similarly-scaled harvest to current private forest regulation specifications would lead to an average increase of 1.45 °C. Further simulations suggested that employing a no-cut slope-distance riparian zone of 27.4 m would result in average warming below 0.3 °C of unharvested conditions. The Board considered these results along with other information and directed the Oregon Department of Forestry to develop harvest rule revisions. Those revisions became effective as of July 2017.

1. Introduction

Stream temperature strongly influences water quality for many biota, affecting community composition, reproductive success, and life histories (see citations in Allan and Castillo, 2007; Sweeney and Newbold, 2014). Timber harvest along riparian areas has often been associated with increases in stream temperatures (Moore et al., 2005; Caissie, 2006; Webb et al., 2008; Sweeney and Newbold, 2014). In the Pacific Northwest, including British Columbia and the U.S. states of Idaho, Washington, Alaska, and Oregon, stream temperature is a water quality concern due to the thermal requirements of native salmonid populations (U.S. Environmental Protection Agency, 2003, B.C. Reg. 14/2004). In response to initial studies demonstrating marked temperature increases following full removal of riparian canopies (e.g., Brown, 1969; Brown and Krygier, 1970), these states enacted timber harvest regulations to protect stream shade, beginning with Oregon in 1972 (Gregory, 1997).

The U.S. Clean Water Act of 1972 (U.S. Water Pollution Control Act Amendments of 1972, sections 101(a) and 303(c)) requires states to "maintain the chemical, physical, and biological integrity of the Nation's waters", including temperature. As the administrator of the Clean Water Act, the U.S. Environmental Protection Agency (EPA; see Table 1 for a list of abbreviations and acronyms) is charged with providing guidance to states to develop compliant water quality regulations (Section 304(a)(7)). In Oregon, the Department of Environmental Quality (ODEQ) developed water quality rules that aligned with the EPA Region 10 guidance (ODEQ, 2004; EPA, 2003). The ODEQ water quality rules contain two sets of criteria that apply to forestry: the Biologically-Based Numeric Criteria and the Protecting Cold Water criterion (Oregon Administrative Rules 340-041-0028(4) and 340-041-0028(11), respectively). The Biologically-Based Numeric Criteria do not permit the warming of streams utilized by salmonids above specified thresholds (e.g., 16 or 18 °C in the Oregon Coast Range). The Protecting Cold Water criterion (PCW) is an anti-degradation standard that prohibits warming of cold waters (below the Biologically-Based numeric Criteria) by more than 0.3 °C. The PCW applies to streams that support salmon (*Oncorhynchus kisutch, O. tshawytscha*), steelhead (*O. mykiss*), and bull trout (*Salvelinus confluentus*) but does not apply to those that

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Table 1
List of acronyms, abbreviations, and their meaning.

Abbreviations	Full name or description
Board	Oregon Board of Forestry
EPA	United States Environmental Protection Agency
FPA	Forest Practice Administrative Rules and Forest Practices Act
GSF	Global Site Factor
NWFMP	State Forest Northwest Forest Management Plan
ODEQ	Oregon Department of Environmental Quality
ODF	Oregon Department of Forestry
PCW	Protecting Cold Water
RipStream	Riparian Function and Stream Temperature Project
RMA	Riparian Management Area
St.	Station, or location of thermistor placement (Fig. 1)
40-day max	Maximum daily stream temperatures averaged over a 40-day period

only support cutthroat trout (*O. clarkii*).

Since solar radiation is a major contributor to stream warming (Webb and Zhang, 1997, 1999; Johnson, 2004), the ODEQ assumes that timber harvests conducted in compliance with the Oregon Forest Practices Act (i.e., follow riparian retention rules; Oregon Department of Forestry, 2014) meet water quality regulations (ODEQ, 2004) by leaving sufficient riparian canopy cover to prevent stream warming. However, the Oregon Department of Forestry (ODF) must verify this assumption through rule effectiveness monitoring (ODF, 2014). To this end, the ODF initiated its Riparian Function and Stream Temperature Project (RipStream) in 2002.

The ODF designed RipStream to examine the effectiveness of harvest conducted according to Oregon's Forest Practice Administrative Rules and Forest Practices Act (FPA; ODF, 2014) and the management plan for state-owned forestland (State Forest Northwest Forest Management Plan [NWFMP]; ODF, 2010) at meeting stream temperature water quality regulations and desired future stand conditions (e.g., generating future large wood for streams). The study collected data before and after harvest along 33 harvested stream reaches and the unharvested control reaches immediately upstream of each harvest. Dent et al. (2008) described pre-harvest RipStream riparian conditions and stream temperatures. Groom et al. (2011a) found an increased probability of PCW exceedance on privately-owned land. They did not find similar evidence on land managed by the state. Groom et al. (2011b) conducted a non-regulatory examination of site data and found that within the first two years post-harvest, privately-owned sites exhibited on average a 0.7 °C increase in stream temperature, while state-owned sites exhibited no increase (0.0 °C). Their study found that shade served as an important component for predicting temperature change in the treatment reach, and that shade itself was associated with riparian stand basal area and tree height.

The Oregon Board of Forestry (Board), whose decisions can alter the FPA, reviewed the findings from Groom et al. (2011a) and ruled that degradation of cold water had occurred on private lands (ODF, 2012). The ruling triggered a procedure (Oregon Revised Statutes 527.714 (5a); ODF, 2014) whose provisions required any alterations to existing rules reflect available scientific information, the results of relevant monitoring, the effectiveness of alternative strategies, and effectively mitigate the issue at hand.

This paper serves two purposes. The first is to demonstrate the development of a stream temperature predictive model that joins separate temperature and shade models, provides reasonable estimates of observed states, appropriately accounts for model and measurement error despite model complexity and data transformations, and feasibly evaluates the effectiveness of different strategies at minimizing temperature increases. The paper's second purpose is to describe model results and how those results were used by the Board to evaluate different proposed management strategies and inform its rule-change procedure.

2. Methods

2.1. Study overview

The ODF conducted RipStream along first- to third-order (headwater) streams on privately owned (18 sites) and state forest (15 sites) lands in the Oregon Coast Range. The study took place between 2002 and 2010. As described in Dent et al. (2008), sites were typically 50–70 years old and dominated by Douglas fir (*Pseudotsuga menziesii*) and red alder (*Alnus rubra*). Forest stands were fire- or harvest-regenerated. Shrubs such as vine maple (*Acer circinatum*), stink currant (*Ribes bracteosum*), salmonberry (*Rubus spectabilis*), and devil's club (*Oplopanax horridus*) dominated canopy openings.

Landowners provided the ODF with a list of 130 planned harvests along riparian areas that could potentially serve as study sites. The Department incorporated all (36) sites that met study design requirements and later removed three sites due to changes in harvest plans. Site requirements are described in Dent et al. (2008) and Groom et al. (2011b). They include the ability to collect at least two years of pre-treatment and five years of post-treatment data at every site, minimum treatment reach lengths of 300 m (although three sites were retained that had treatment reaches between 273 m and 300 m in length), and assurance that the upstream "control" reaches would remain unharvested for the duration of the study. Streams needed to qualify as small or medium (mean annual streamflow < 57 or between 57 and 283 L/s, respectively; ODF, 2014), and be free of significant recent impacts from debris torrents and active beaver ponds. The site-selection process prohibited a sampling protocol that allowed for geographic statistical inference. We assume that sites were geographically representative and that the inferential scope of study results pertain to first- to third-order fish-bearing streams within the Coast Range, with 50–70-year-old non-federal forestlands primarily managed for timber production that lack significant, recent debris torrent or beaver disturbance. If sites are not representative of region-wide treatment reach lengths, riparian vegetation characteristics, initial stream temperature distributions, or other attributes, the study's results could be biased and under- or over-predict stream temperature responses.

Each selected stream had three to four Optic Stowaway Temp or HOBO Water Temp Pro data loggers (Onset Computer Corporation, Bourne, Massachusetts) deployed that demarcated treatment and control areas. Between the two thermistors farthest upstream (Station (St.) 1 and St. 2) lies the control reach (Fig. 1). This section of stream

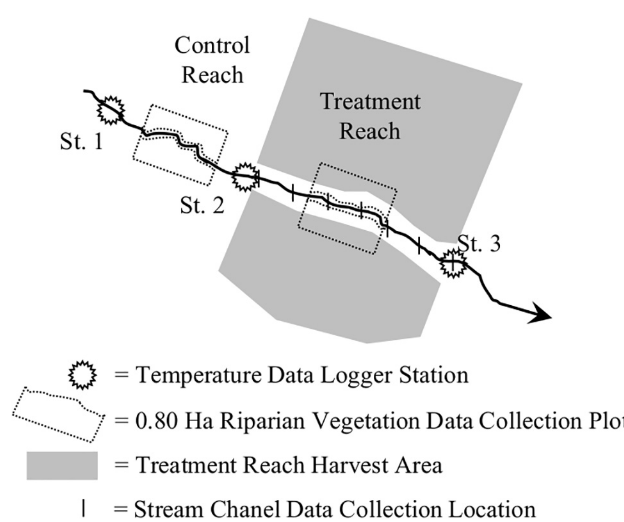

Fig. 1. RipStream site layout. Control and treatment reach boundaries are defined by the position of Station (St.) 2 and 3 temperature data loggers. Two riparian vegetation data collection plots are situated midway along both the control and treatment reaches. Stream channel data collection locations are placed at 61 m intervals starting at St. 3.