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A catchment-scale assessment of stream temperature response to contemporary forest harvesting in the Oregon Coast Range

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ABSTRACT

Historical forest harvesting practices, where the riparian canopy was removed, generally increased energy loading to the stream and produced higher stream temperatures. As such, contemporary forest management practices require maintenance of streamside vegetation as riparian management areas, with an important function of providing shade and minimizing solar radiation loading to streams to mitigate stream water temperature changes. The Alsea Watershed Study Revisited in the Oregon Coast Range provided a unique opportunity to investigate and compare the stream temperature responses to contemporary forest harvesting practices (i.e., maintenance of riparian vegetation) with the impacts from historical (1960s) harvesting practices (i.e., no riparian vegetation). Here we present an analysis of 6 years (3 years pre-harvest and 3 years post-harvest) of summer stream temperature data from a reference (Flynn Creek) and a harvested catchment (Needle Branch). There was no evidence that the (a) 7-day moving mean of daily maximum ($T_{7DAYMAX}$) stream temperature, (b) mean daily stream temperature, or (c) diel stream temperature changed in the study stream reaches following contemporary forest harvesting practices. The only parameter of interest that changed after forest harvesting was the $T_{7DAYMAX}$ when analyses were constrained to the Oregon regulatory period of July 15 to August 15 and all sites in each catchment were grouped together—in this case stream temperature increased 0.6 ± 0.2 °C ($p = 0.002$). However, over the entire post-harvest study period, the warmest maximum daily stream temperature observed in Needle Branch was 14.7 °C—in the original Alsea Watershed Study, maximum daily stream temperatures rose to 21.7 °C (1966) and 29.4 °C (1967) in the first two post-harvest years, providing evidence that current harvesting practices have improved protection for stream water temperatures.

1. Introduction

Preventing or mitigating changes in the thermal regime following land use activities, such as forest harvesting, is a primary focus of contemporary forest watershed management (Hester and Doyle, 2011). Historical research has shown that forest harvesting, where the riparian canopy is removed, can increase energy loading to the stream and produce higher stream temperatures (Levno and Rothacher, 1967; Moore et al., 2005; Studinski et al., 2012). The original Alsea Watershed Study (AWS; 1958–1973) in the Oregon Coast Range demonstrated that clear-cut harvesting with complete removal of riparian vegetation can result in dramatic changes in mean daily, maximum daily, diurnal variation, and annual patterns in stream temperature (Brown and Krygier, 1970). Strips of vegetation left along Deer Creek in the original AWS also demonstrated the benefit of streamside trees for reducing the impacts of forest harvesting on stream temperature (Brown and Krygier, 1970; Ice et al., 2004; Ice, 2008). Results from this historical research were instrumental to the creation of the Oregon Forest Practices Act of 1971, which called for retention of streamside vegetation (18–30 m riparian management zones) in private harvest units as a best management practice for the maintenance of water quality and aquatic habitat (Ice and Stednick, 2004).

One of the most desirable functions of riparian areas is to maintain water temperatures after forest harvesting by minimizing solar radiation input to streams (Hester and Doyle, 2011). This is because stream temperature is one of the most important physical water quality parameters that can influence the structural and functional characteristics of stream and river aquatic ecosystems (Vannote et al., 1980; Poole and Berman, 2001; Clarke, 2006). Stream temperatures affect the metabolic and physical processes of aquatic organisms (Brown et al., 2004; Leach et al., 2012), the behavioral ecology of aquatic organisms (Torgersen et al., 1999;

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Wenger et al., 2011), and the rates of in-stream chemical processes (Demars et al., 2011). As such, stream temperature is a fundamental determinant of habitat for most aquatic organisms, including phytoplankton, zooplankton, macroinvertebrates, and fish (Beitinger and Fitzpatrick, 1979; Vannote and Sweeney, 1980). Cold-water fish species, such as Pacific salmonids, are adapted to the spatial and temporal temperature patterns experienced in their native ranges and are particularly sensitive to fluctuations in water temperature through all stages of their life history (Dunham et al., 2003; McCullough et al., 2009). Rapid and extreme alterations in water temperature regimes can result in dispersal, increased vulnerability to predation, acute thermal shock, or mortality (Beschta et al., 1987; Quigley and Hinch, 2006).

Recent experiments have shown that riparian management areas (RMAs) consisting of mature timber that preserves some percentage of pre-harvest canopy closure to maintain stream shade may be effective at minimizing the effects of forest harvesting on stream temperature (Macdonald et al., 2003; Gomi et al., 2006; Groom et al., 2011; Cole and Newton, 2013). 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 still, however, considerable debate and uncertainty about the effectiveness of contemporary practices and the design of buffers (DeWalle, 2010; Newton and Ice, 2016). In part, this is due to the lack of scientific underpinnings for riparian guidelines in many regions (Blinn and Kilgore, 2001). While many jurisdictions vary widely in their riparian buffer guidelines due to differences in climate, economic, and social factors (Lee et al., 2004), many have simply adopted regulations from other forested landscapes without any empirical research to test their local efficacy (Richardson et al., 2012). Since much of the understanding on the effectiveness of riparian forest buffers originates from studies examining historical (middle 20th century) forest harvesting practices, these results do not accurately reflect contemporary practices (Brown and Krygier, 1971; Holtby, 1988; Johnson and Jones, 2000). As such, further analysis is needed to assess the effectiveness of contemporary forest management practices at mitigating the impacts on stream temperature.

The Alsea Watershed Study Revisited provided a unique opportunity to investigate and compare the stream temperature responses to contemporary forest harvesting practices (e.g., retention of riparian vegetation for provision of shade) with the impacts from historical (1960s) harvesting practices (e.g., no riparian vegetation retained). The AWS was reactivated in 1990 to assess long-term responses of the catchments to commercial forest harvesting (Stednick, 2008). As an extension of the reactivation of the site, a study of current forest harvest practices on private timberlands began in 2006. The upper portion of the Needle Branch catchment was harvested in 2009 according to the Oregon Forest Practices Act, including RMAs. Here, we present analysis of 6 years (3 years pre-harvest and 3 years post-harvest) of summer stream temperature data from the reference (Flynn Creek) and harvested catchments (Needle Branch) to address three research questions:

(1) Did the 7-day moving mean of daily maximum ($T_{7DAYMAX}$) stream temperature change following contemporary forest harvesting?
(2) Did mean daily stream temperature (T_{DAY}) change following contemporary forest harvesting?
(3) Did the diel stream temperature (T_{DIEL}) change following contemporary forest harvesting?

2. Methods

2.1. Site description

The Alsea Paired Watershed Study Revisited (44.5°N, 123.9°W) was constructed as a paired-watershed study (Fig. 1), with a reference catchment (Flynn Creek, 219 ha) and a nearby treatment catchment (Needle Branch, 94 ha), which was harvested in 2009 with RMAs according to the Oregon Forest Practices Act (OFPA) (Table 1). The study area is located in the Siuslaw National Forest in the Oregon Coast Range, which is highly-dissected and mountainous and characterized by short, steep, soil-mantled hillslopes. Both catchments are underlain by Eocene Tyee Formation sandstone and siltstone. Mean elevation in Flynn Creek is 280 m and in Needle Branch is 220 m. The mean gradient of Flynn Creek is 27.9°, while Needle Branch is considerably steeper at 37.0°. Drainage density in Flynn Creek is 0.47 km km^{-2}, while in Needle Branch it is 1.01 km km^{-2}. In Flynn Creek, the mean wetted width was 1.34 m ± 0.11 SD with mean maximum pool depths of 0.25 m ± 0.03 SD and mean maximum riffle depths of 0.09 m ± 0.02 SD. In Needle Branch, the mean wetted width was 1.11 m ± 0.15 SD with mean maximum pool depths of 0.25 m ± 0.04 SD and mean maximum riffle depths of 0.07 m ± 0.02 SD. Stream wetted widths and depths are representative of typical summer baseflow conditions, during the peak summer temperature period, in the Oregon Coast Range. The channel substrate in Flynn Creek primarily consisted of gravels (42.6% ± 0.08 SD) and fines (<1 mm; 19.1% ± 0.04 SD) with lesser amounts of cobbles, boulders, and bedrock. Similarly, Needle Branch is also primarily gravels (45.0% ± 0.10 SD) and fines (<1 mm; 28.9% ± 0.08 SD) with occasional cobbles, boulders, and bedrock. Catchments are principally south facing, with mean slope aspects of 188° in Flynn Creek and 189° in Needle Branch.

Forest vegetation in Needle Branch was primarily even-age (44-yr-old), dominated by Douglas-fir (*Pseudotsuga menziesii*) with patches of red alder (*Alnus rubra*) along the riparian corridors. Forest vegetation in Flynn Creek is ~155-yr-old Douglas-fir with stands of red alder dominating the riparian corridor. Study catchments support fish communities of coastal cutthroat trout (*Oncorhynchus clarkii clarkii*), coho salmon (*O. kisutch*), reticulate sculpin (*Cottus perplexus*), western brook lamprey (*Lampetra richardsoni*), and Pacific lamprey (*L. tridentata*).

Flynn Creek is principally undisturbed by human activities (during the 1960s study as well as today) and was designated as a Research Natural Area in 1975 by the USDA Forest Service. The upper sub-catchment (37.2 ha) of Needle Branch was clearcut harvested from mid-June to mid-August 2009 using contemporary harvesting practices, including both ground-based and line-based equipment. All trees in the cutover area were removed, including along 3 small, non-fish-bearing tributaries that join to form mainstem Needle Branch just above a waterfall that forms the upstream limit of fish distribution. On the fish-bearing portion of the stream, a ~15 m riparian management area (RMA) was retained on each side of Needle Branch in accordance with the Oregon Forest Practices Act and Rules (ODF, 1994). This resulted in a minimum of ~3.7 m^2 conifer basal area retained for every ~300 m of stream length. In addition, ~4–5 wildlife leave trees per hectare were retained within the RMA, as recommended by the Oregon Forest Practices Act (Adams and Storm, 2011). Mean canopy closure, as measured with a densiometer, along the stream channel in the harvested portion of Needle Branch was reduced from ~96% in the pre-harvest period to ~89% in the post-harvest period. Comparatively, mean canopy closure along the stream channel in Flynn Creek was ~92% in the pre-harvest period and ~91% in the post-harvest period.