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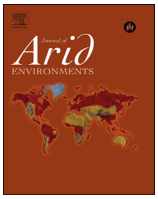

Spatial and temporal variability in the effects of wildfire and drought on thermal habitat for a desert trout

L.D. Schultz [a], M.P. Heck [a], D. Hockman-Wert [a], T. Allai [b], S. Wenger [c], N.A. Cook [d],
J.B. Dunham [a, *]

[a] Forest and Rangelands Ecosystem Science Center, U.S. Geological Survey, Corvallis Research Group, 3200 SW Jefferson Way, Corvallis, OR 97331, USA
[b] Bureau of Land Management, 100 Oregon St., Vale, OR 97918, USA
[c] Odum School of Ecology, The University of Georgia, 104 E. Green Street, Athens, GA 30602, USA
[d] Forest Engineering, Resources, and Management, College of Forestry, Oregon State University, 280 Peavy Hall, Corvallis, OR 97331, USA

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ABSTRACT

We studied how drought and an associated stressor, wildfire, influenced stream flow permanence and thermal regimes in a Great Basin stream network. We quantified these responses by collecting information with a spatially extensive network of data loggers. To understand the effects of wildfire specifically, we used data from 4 additional sites that were installed prior to a 2012 fire that burned nearly the entire watershed. Within the sampled network 73 reaches were classified as perennial, yet only 51 contained surface water during logger installation in 2014. Among the sites with pre-fire temperature data, we observed 2–4 °C increases in maximum daily stream temperature relative to an unburned control in the month following the fire; effects (elevated up to 6.6 °C) appeared to persist for at least one year. When observed August mean temperatures in 2015 (the peak of regionally severe drought) were compared to those predicted by a regional stream temperature model, we observed deviations of −2.1°-3.5°. The model under-predicted and over-predicted August mean by > 1 °C in 54% and 10% of sites, respectively, and deviance from predicted was negatively associated with elevation. Combined drought and post-fire conditions appeared to greatly restrict thermally-suitable habitat for Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*).

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1. Introduction

The influences of climate on Earth are often portrayed as systematic trends through time (Loarie et al., 2009), but change itself is not stationary (Milly et al., 2008). For example, as climate changes, it is broadly anticipated that the probability of episodic disturbances will also change (Running, 2008). Ecologically, this means that species will have to contend with a host of acute and chronic exposures (Foden et al., 2013) to changing climates. Such uncertainties regarding climate itself provide many challenges for anticipating ecological responses to climate change (Wenger et al., 2013). Here we focus on two common episodic, climate-driven ecological disturbances: drought (Lake, 2011) and wildfire (Westerling, 2016). Both of these disturbances are driven by the intersection of precipitation deficits and warm temperatures, and are thus likely to manifest at the same time within a given area (Diffenbaugh et al., 2015; Ganguli and Ganguly, 2016).

In this study we consider the influences of drought and wildfire on stream temperatures. Stream temperature is well-known to be sensitive to both meteorological variability (i.e. drought-related; Caissie, 2006; Diabat et al., 2013; Luce et al., 2014) and wildfires (Hitt, 2003; Dunham et al., 2007; Mahlum et al., 2011). In the northern Great Basin desert, the onset of meteorological and hydrological drought (Wilhite and Glantz, 1985) has increasingly coincided with large wildfires (Denison et al., 2014; Westerling, 2016). Wildfires often burn riparian vegetation, leading to loss of shade and warming of stream temperatures (Dunham et al., 2007; Mahlum et al., 2011), which may further warm if streams experience reduced flows during drought. Because a host of factors can influence stream temperatures and sensitivity to drought and wildfire (e.g., riparian and topographic shading, surface-subsurface

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* Corresponding author.
E-mail addresses: mheck@usgs.gov (M.P. Heck), tallai@blm.gov (T. Allai), swenger@uga.edu (S. Wenger), nickcook@oregonstate.edu (N.A. Cook), jdunham@usgs.gov (J.B. Dunham).

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heat fluxes) specific responses can be variable and difficult to predict. We used a combination of opportunistically available records of stream temperature (from temperature data loggers in operation before and after a large wildfire), a regional model of stream temperatures from before a wildfire and drought (Isaak et al., 2016a), and a network of temperature loggers deployed after a fire and during the height of an ongoing drought (i.e., 2015; Fig. 1) to evaluate how both wildfire and drought influenced temperatures across a large, desert stream network.

Specifically, our objectives were to: 1) quantify the magnitude and duration of influences of wildfire on stream temperature at sites with pre- and post-wildfire temperature data, 2) evaluate spatial variation in responses of summer stream temperature throughout the entire stream network during the latter stages of the drought to a baseline of predictions from a stream temperature model assembled with data from 1993 to 2011 (Isaak et al., 2016a), and 3) assess the ecological consequences of conditions observed during the 2015 drought year for a sensitive species (Lahontan cutthroat trout, [*Oncorhynchus clarkii henshawi*]; Jones et al., 1998). Collectively, results of this work provide novel insights into how aquatic ecosystems respond to the combined influences of drought and wildfire, two interactive disturbances that are more likely to occur as climate change proceeds (Lake, 2011; Diffenbaugh et al., 2015; Westerling, 2016).

2. Methods

2.1. Study area

Our study was focused in the Willow and Whitehorse creeks watershed (hereafter, Willow-Whitehorse watershed) of southeast Oregon (Fig. 2). The watershed is characteristic of Great Basin sagesteppe, consisting mostly of open rangelands with elevations of 1300–2250 m, including 200–400 m deep canyons draining northward into the endorheic Coyote Lake Basin (Grayson, 2011). The watershed contains 262 km of intermittent-classified stream channels in the National Hydrography Dataset Plus V2 (NHDPlus; USEPA, 2012), and an additional 143 km of NHDPlus-classified perennial stream channels (all mapped at 1:100,000 scale). Natural overstory vegetation across the watershed is typical of the region and composed of mostly sagebrush *Artemisia* spp. and pockets of quaking aspen *Populus tremuloides* in the higher elevations, bitterbrush *Purshia tridentata* and rabbitbrush (family: Asteraceae) flats at lower elevations, and willow *Salix* spp. dominated riparian zones (Grayson, 2011). Non-native cheatgrass *Bromus tectorum* has also invaded into much of the watershed, displacing native bunchgrasses (family: Poaceae) and has potentially altered its susceptibility to wildfire (Knapp, 1996). The watershed is also notable in that it supports one of the largest extant populations of Lahontan cutthroat trout *Oncorhynchus clarkii henshawi* (Jones et al., 1998; Warren et al., 2014), a federally listed threatened taxon (USFWS, 1995).

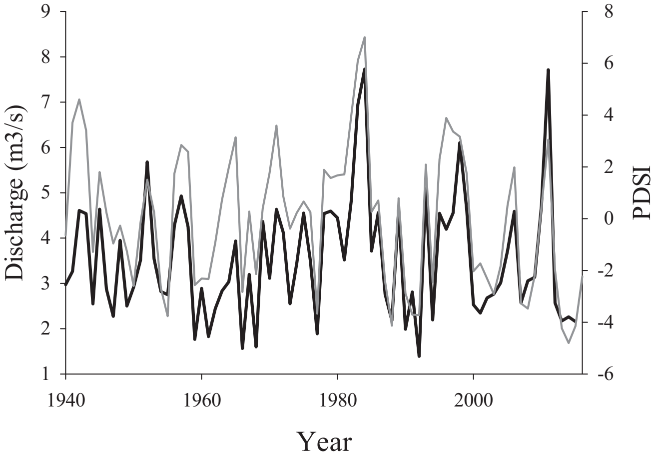

Fig. 1. Palmer Drought Severity Index (PDSI; gray) and annual discharge (m^3/s; black) for southeast Oregon, 1940–2016. Drought severity is from the Southeast Oregon climate division (3509) for this period of record, with monthly values aggregated to annual means to visualize general meteorological drought conditions in the region. Annual discharge is from the Donner und Blitzen River (10396000) in the Steens Mountain region, 70 km northwest of Willow-Whitehorse watershed.

Our study system represents a progression of conditions associated with development of drought as a meteorological, hydrologic, and ecological phenomenon (Wilhite and Glantz, 1985). As with much of the western United States (Mote et al., 2016; Ganguli and Ganguly, 2016), the Willow-Whitehorse watershed experienced a period of severe meteorological drought that began in 2012 and peaked in 2015. The Palmer drought severity index (PDSI) suggested this was one of the most severe droughts on record in this watershed (Fig. 1). When combined with summer heat that is typical of the northern Great Basin (Hidy and Klieforth, 1990), these two factors led to manifestation of hydrologic drought, as evident from declining annual stream discharge recorded at a nearby gage in the Donner und Blitzen River, Oregon (Fig. 1). As drought conditions in the region intensified, major wildfires also occurred (Westerling, 2016). In the Willow-Whitehorse watershed, the Holloway Fire occurred August 5–17, 2012, and burned over 185,000 ha in northwest Nevada and southeast Oregon, including over 85% of our study area (Fig. 2). The fire resulted in significant loss of vegetation in both upland and riparian habitats (Fig. 3), and resulted in a mosaic of burn intensities across the Willow-Whitehorse watershed (P. Donnelly, University of Montana, unpublished data).

2.2. Field data collection

We quantified spatial variation in stream temperatures by deploying a network of data logging sensors in the Willow-Whitehorse watershed September 24–27, 2014. We allocated 100 sampling points across stream reaches classified as perennial and intermittent by NHDPlus, and addressed specific research questions by ensuring that points represented several stratified landscape characteristics. We initially selected 7 locations within livestock exclosures to address management-related questions in the watershed. The remaining 93 sample locations were drawn from across the watershed using a generalized random tessellation stratified (GRTS) master sample created for the State of Oregon (Larsen et al., 2008). Use of the master sample was intended for distributing points across the stream network, rather than for generating unbiased estimates of conditions within the stream network based on known probabilities of inclusion for each point. Of the 100 sample points, 67 were selected from NHDPlus perennial streams and 33 in reaches classified as intermittent. We also selected these points such that 75 points were located inside and 25 outside of the perimeter of the Holloway Fire, and 50 inside and 50 outside of the Lahontan cutthroat trout distribution delineated during fisheries surveys conducted by Oregon Department of Fish and Wildlife (ODFW) between 2011 and 2013 (Jones et al., 1998; Kim Jones, ODFW, personal communication). This approach allowed us to attain a reasonable degree of spatial dispersion of points across the watershed, and to represent conditions believed to potentially influence hydrologic (stream flow permanence) or ecological (trout distribution) factors that could relate to stream temperature. In addition to these 100 points, 10 supplemental

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