Journal of Environmental Management 139 (2014) 32–37

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Mountain pine beetle infestation of lodgepole pine in areas of water diversion

Sharon L. Smolinski [a,*], Peter J. Anthamatten [a], Leo P. Bruederle [b], Jon M. Barbour [a], Frederick B. Chambers [a]

[a] University of Colorado Denver, Department of Geography and Environmental Sciences, Campus Box 172, P.O. Box 173364, Denver, CO 80217-3364, USA
[b] University of Colorado Denver, Department of Integrative Biology, Campus Box 171, P.O. Box 173364, Denver, CO 80217-3364, USA

ARTICLE INFO

Article history:
Received 11 July 2013
Received in revised form
21 January 2014
Accepted 23 February 2014
Available online 26 March 2014

Keywords:
Mountain pine beetle
Water diversions
Lodgepole pine
Rocky mountains
Tree mortality
Water management

ABSTRACT

The Rocky Mountains have experienced extensive infestations from the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), affecting numerous pine tree species including lodgepole pine (*Pinus contorta* Dougl. var. *latifolia*). Water diversions throughout the Rocky Mountains transport large volumes of water out of the basins of origin, resulting in hydrologic modifications to downstream areas. This study examines the hypothesis that lodgepole pine located below water diversions exhibit an increased incidence of mountain pine beetle infestation and mortality. A ground survey verified diversion structures in a portion of Grand County, Colorado, and sampling plots were established around two types of diversion structures, canals and dams. Field studies assessed mountain pine beetle infestation. Lodgepole pines below diversions show 45.1% higher attack and 38.5% higher mortality than lodgepole pines above diversions. These findings suggest that water diversions are associated with increased infestation and mortality of lodgepole pines in the basins of extraction, with implications for forest and water allocation management.

1. Introduction

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) has severely impacted pine species throughout the western USA and Canada in recent years, resulting in large regions with damaged and dead pine trees (Raffa et al., 2008; Logan et al., 2010). Increased mountain pine beetle (MPB) populations are supported by increased temperatures, as well as increased stand density facilitated by fire suppression (Raffa et al., 2008; Negron et al., 2009; Bentz et al., 2010; Logan et al., 2010; Kulakowski et al., 2012). These conditions are compounded by decreased resistance of host trees to bark beetle species due to factors such as drought, increased temperatures, and pollution deposition (Mattson and Hacck, 1987; Jones et al., 2004; Raffa et al., 2008; Bentz et al., 2010; Logan et al., 2010; McDowell et al., 2011). Drought can alter the chemical and physical properties of resin, a key defense mechanism, thereby reducing resistance of the host tree to infestation (Mattson and Haack, 1987; Raffa et al., 2008; McDowell et al., 2011). Specifically, drought impairs resin flow and pressure, properties that can impede beetles, as well as the concentration of chemicals that are toxic to beetles (ibid). Climate change is contributing to both increased temperatures and decreased water availability, thereby increasing conditions that favor MPB infestation (Raffa et al., 2008; Bentz et al., 2010; Logan et al., 2010; McDowell et al., 2011).

Water diversion projects extend throughout the Rocky Mountain region, transporting significant volumes of water out of the basins of origin. In Colorado, numerous systems collect and transport water from the western side of the Continental Divide to the eastern side, servicing the Front Range (Colorado's Decision Support System [CDSS], n.d.). In Grand County, CO, water is diverted from all major basins in the southern and eastern portions of the county using vast systems of dams, canals, and pipelines, based on data from Colorado's Decision Support System (n.d.), as well as survey data gathered during this study. Dams function to block and collect water from streams, and funnel the water into the diversion canals and pipes. Canals function to transport water, and also collect surface and subsurface flow (Natural Resources Conservation Service [NRCS],

* Corresponding author. Present address: University of Colorado Denver, The School of Public Affairs, 1380 Lawrence St., Suite 500, Denver, CO 80204, USA. Tel.: +1 303 919 2806; fax: +1 303 315 2229.

E-mail addresses: sharon.smolinski@ucdenver.edu (S.L. Smolinski), peter.anthamatten@ucdenver.edu (P.J. Anthamatten), leo.bruederle@ucdenver.edu (L. P. Bruederle), jon.barbour@ucdenver.edu (J.M. Barbour), frederick.chambers@ucdenver.edu (F.B. Chambers).

http://dx.doi.org/10.1016/j.jenvman.2014.02.034
0301-4797/

2010), particularly from a slope (Texas A&M Forest Service, 2008). The area examined in this study contains a portion of the Moffat Tunnel diversion system, which collects from all of the headwaters of the Fraser River (Colorado Division of Wildlife [CDOW], 2010; CDSS, n.d.). This system carried an average of 2.16 cubic meters per second from June 1958 through May 2010, and 2.29 cubic meters per second during the 10-year period prior to this study, based on stream flow data from the east side of the Moffat Tunnel (Colorado Division of Water Resources [CDWR], 2013). This system removes a significant portion of water from the natural river system, based on comparisons of historic stream flow data (Coley/Forrest, Inc, 2007). In a nearby system, researchers have noted that all water is diverted from some streams in some years, resulting in "dry conditions below diversions" (CDOW, 2010).

Substantial research has provided evidence that water diversions cause measureable changes to stream habitat, including reduced water flow, structural barriers to wildlife movement, altered streambed characteristics, increased water temperatures and altered populations of species dependent on riparian ecosystems (Osmundson et al., 2002; Covington and Hubert, 2003; Uowolo et al., 2005; Hagen and Sabo, 2012). Estuarine habitats downstream from diversion points have been adversely impacted from reduced flow (Carriquiry and Sanchez, 1999; Rodriguez et al., 2001; Schöne et al., 2003). Diverted streams with reduced flow also show reduced fish (Osmundson et al., 2002) and bat populations (Hagen and Sabo, 2012), in conjunction with reduced aquatic insect populations. Dams reduce species diversity of downstream riparian plant communities (Uowolo et al., 2005). Diversions in high-elevation basins can lower the water table and alter carbon cycling in alpine wetlands (Chimner and Cooper, 2003). In Grand County, CO, researchers have noted impacts to fish and invertebrates due to decreased stream flow caused by diversions (CDOW, 2010). However, little work has examined the impacts of diversions on coniferous species in mountain basins or potential correlations between diversions and MPB activity.

The goal of this study was to determine if there is an association between water diversions and MPB infestation and subsequent tree mortality. Since water diversions cause reduced water availability below diversion points, we expect a reduction in resistance of lodgepole pines to MPB infestation within stands located below diversions, manifested by increased incidence of attack and mortality. This study measured MPB infestation and mortality in lodgepole pines above and below water diversions in order to determine if a correlation exists. Increased infestation and mortality below diversions would suggest a need to improve our understanding of the ecosystem impacts of water diversions, and potentially modify water allocation strategies.

2. Materials and methods

2.1. Study area

The study area is located in the southeast portion of Grand County, CO in the Sulphur Ranger District, Arapahoe National Forest, west of the Continental Divide (Fig. 1). The area has mixed land cover, with forests of lodgepole pine (*Pinus contorta* Douglas ex Loudon var. *latifolia* Engelmann), Englemann spruce (*Picea engelmannii* Parry ex Engelmann), subalpine fir (*Abies bifolia* A. Murray), and quaking aspen (*Populus tremuloides* Michaux). Precipitation and temperature data for the area are monitored at a nearby SNOTEL site at 39°55′N, 105°46′W and 2950.5 m in elevation (National Water and Climate Center [NWCC], 2012). The historical mean annual air temperature is 2.9 °C (October 1986–September 2011), and the historical mean annual accumulated precipitation is 35.1 cm (NWCC, 2012). During 2010, the year of our field sampling, the mean annual air temperature was 3.3 °C and the mean annual accumulated precipitation was 25.1 cm (January to December 2010) (NWCC, 2012).

In order to determine the types and locations of diversion structures and vegetation, ground surveys covering 33.8 km in total distance were conducted along diversions in three areas in south and southeast Grand County, CO. One area was selected for this study (Fig. 1), because it contained lodgepole pine and a portion of the Moffat Tunnel diversion system. This system uses dams, canals, and pipelines to collect from all headwaters of the Fraser River (CDOW, 2010; CDSS, n.d.). This system first started exporting water across the Continental Divide through the Moffat Tunnel in 1936, and significant additions were made to the system through 1958 (Denver Water, 2013). Diversions were inventoried using a digital camera and a global positioning system (GPS) unit (GPSmap 60CSx, Garmin) with an accuracy of 2.7–3.7 m. Dirt roads provide access along the diversion system.

2.2. Site selection

Three study sites were selected based on the aforementioned ground survey data. One site was established around a dam (Site A), and two sites were established around canals (Sites B and C). A total of 14 plots were established across those sites, surveyed between July and September 2010. At the two sites bisected by a canal, plots were established above and below the canal, with plot centers approximately 18.3 m from the canal edge or adjacent road. At the dam site, plots were established above and below the dam, with plot centers approximately 10.7 m from the stream edge. Circular plots did not overlap and had a radius of 9.75 m (298.65 m^2, 0.03 ha), similar to plots used in related studies (e.g., Breece et al., 2008; Morehouse et al., 2008; Negron et al., 2008; Klutsch et al., 2009; Negron et al., 2009). The distance separating above-diversion and below-diversion plots that were situated across from one another, with a canal between them, was approximately 48.8–61.0 m. The distance separating above-diversion and below-diversion plots around the dam was greater than the distance between the canal plots. Plots did not contain evident and current human disturbances other than the active diversion structures. While the long-term history of fire and other disturbance events in this area is unclear, our design with close proximity between plot types at a site presupposes a similar disturbance history.

2.3. Plot measurements

Elevation, aspect, and location were measured at the central point of each plot with the GPS. Slope was estimated using a slope meter. For all standing trees with ≥2.54 cm diameter breast height (DBH), measured at 1.37 m above the ground, DBH and species were recorded. Also, all lodgepole pines with DBH ≥2.54 cm were visually assessed for MPB infestation using the following indicator ratings: living trees without indicators (1 = alive, not attacked), trees with indicators and a majority of green needles (2 = attacked but alive), trees with indicators and majority or entirety of brown or missing needles (3 = beetle-killed), trees dead from indeterminate or non-MPB cause (4 = dead). Indicators of MPB infestation were characterized by bore or exit holes, boring debris at the base of the tree, or pitch tubes. Since trees with small DBH are generally considered less likely to be attacked (Amman, 1977), researchers have often applied a cutoff DBH value in order to exclude small DBH trees from analysis (Breece et al., 2008; Waring and Six, 2005). In this study, only MPB infestation indicator data for lodgepole pines with DBH ≥7.62 cm were utilized for analysis of MPB infestation. This value is in the middle of the range of DBH values (2.54–13 cm) utilized in studies assessing MPB in ponderosa pine (Negron et al.,