Limnologica 47 (2014) 7–20

Contents lists available at ScienceDirect

Limnologica

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

Replacement of culvert styles has minimal impact on benthic macroinvertebrates in forested, mountainous streams of Northern California

Justin E. Lawrence[a,*], Matthew R. Cover[b], Christine L. May[c], Vincent H. Resh[a]

[a] Department of Environmental Science, Policy, and Management, University of California, Berkeley, 137 Mulford Hall #3114, Berkeley, CA 94720, USA
[b] Department of Biological Sciences, California State University, Stanislaus, One University Circle, Turlock, CA 95382, USA
[c] Department of Biology, James Madison University, MSC 7801, Harrisonburg, VA 22807, USA

ARTICLE INFO

Article history:
Received 26 July 2013
Received in revised form 11 February 2014
Accepted 13 February 2014
Available online 13 March 2014

Keywords:
Road-stream crossing
Culvert removal
Forest roads
Benthic macroinvertebrates
Mountainous streams

ABSTRACT

Culvert styles are being replaced on many road-stream crossings to provide long-term (>2 years) benefits, but these projects may result in short-term (0–2 years) biological impacts. We quantified the short-term effects of replacing steel-pipe culverts with open-arch structures on the benthic-macroinvertebrate communities of 6 streams in the Klamath National Forest of Northern California USA. Physical habitat showed notable site-specific effects in channel form and sedimentation, but no significant change among sites. In contrast, we observed small though significant impacts of the culvert style replacement on benthic macroinvertebrates among sites, including a statistically significant reduction in both taxa richness ($p = 0.012$) and abundance of intolerant taxa ($p = 0.004$). Moreover, there was also modest evidence of slightly elevated variability in the benthic-macroinvertebrate communities downstream following the replacement of culvert style. The long-term benefits of culvert style replacement that have been observed in other studies may outweigh the minor, short-term biological impacts observed in these streams.

Introduction

Freshwater biota of forested, mountainous streams often have life cycles that are finely adapted to the environmental conditions characteristic of these regions. For example, many migratory fishes, such as salmonids, begin their life cycles in these streams and later migrate to larger rivers, and in some cases the ocean, during their adult life stages before returning to spawn (Huusko et al. 2007). Benthic macroinvertebrates, which are a primary food source for many of these fishes (Wipfli and Baxter 2010), and are also widely used as indicators of stream ecological-health (Resh and Jackson 1993), have specialized traits that are adapted to these mountainous environments (Richardson and Daheny 2007; Poff et al. 2010). Although benthic-macroinvertebrate communities are both resistant and resilient to the natural stresses of their environment (Robinson 2012), including low temperatures and turbulence, they may be impacted if placed under the additional burden of anthropogenic stress (Novotny et al. 2005). If this occurs, they can experience variability in population and community metrics that is outside of the natural range, which can be described using coefficients of variation (Resh et al. 2013).

Many but not all culverts under forest roads act as a perturbation agent in montane (or lower) stream systems. For example, they can act as migration barriers (Thompson and Lee 2000; Kemp and O'Hanley 2010; Nislow et al. 2011), and can disrupt food-web linkages between aquatic and terrestrial ecosystems (Switalski et al. 2004; Doi 2009). Moreover, when road-stream crossings fail as a result of inadequate culvert design, large pulses of sediment or debris flows can enter streams (Wemple et al. 2001), impacting both benthic macroinvertebrate (Cover et al. 2008) and salmonid (Lamberti et al. 1991; Roghair et al. 2002) biodiversity. Khan and Colbo (2008) found that stream culverts primarily impacted benthic macroinvertebrate taxa abundance rather than community composition. Replacement of culvert styles in streams can reduce migration barriers and prevent upstream loss of diadromous fauna (Resh 2005). Regulatory guidelines are important for reducing risk in such projects (Cocchiglia et al. 2012).

Forest roads are present throughout the world, and are planned and constructed for diverse reasons and maintained to different extents (e.g., Akay et al. 2008; Gumus et al. 2008; Laurance et al.

* Corresponding author. Tel.: +1 510 642 5913; fax: +1 510 642 7428.
E-mail addresses: jlawrence@berkeley.edu, justin.earl.lawrence@gmail.com (J.E. Lawrence), mcover@csustan.edu (M.R. Cover), maycl@jmu.edu (C.L. May), resh@berkeley.edu (V.H. Resh).

http://dx.doi.org/10.1016/j.limno.2014.02.002
0075-9511/

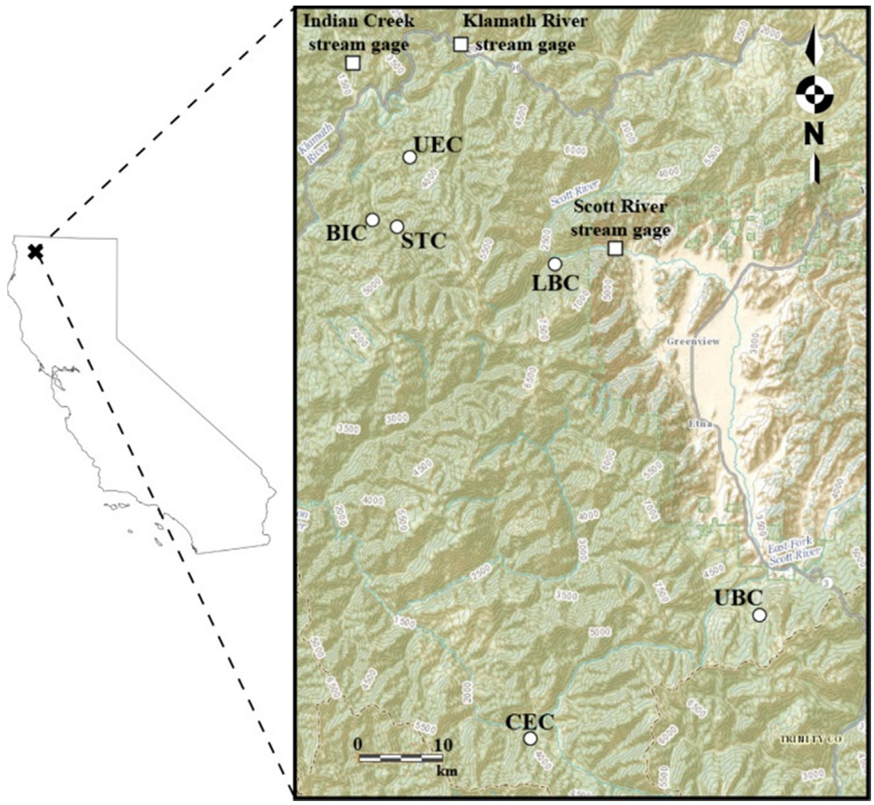

Fig. 1. Location of the 6 study sites (3 letter codes defined in Table 1), 3 stream gages, local towns, main roads, and primary streams in the Klamath National Forest, Northern California.

2009). In the United States, approximately 700,000 km of paved and unpaved forest roads are located on United States Forest Service (USFS) lands (Madej 2001; Elseroad et al. 2003). Many of these roads were constructed for timber extraction, which peaked on these lands in the 1970s–1980s. In recent decades, however, a large number of them are infrequently used and not actively maintained (USFS 2001), resulting in widespread erosion problems and negative impacts to habitat (Amaranthus et al. 1985; Furniss et al. 1998; Cafferata et al. 2007).

Replacement of steel-pipe culverts along such roads with open-arch structures is a rehabilitation practice that is often performed in U.S. National Forests with aquatic-habitat enhancement being among the chief goals (Ice 2004). These rehabilitation projects are often performed following Best Management Practices (BMPs), which typically aim to have no short-term, negative effects on aquatic biota. However, the effectiveness of these BMPs in preventing short-term (0–2 years) biological impacts has not been examined in detail (Luce and Wemple 2001). Over the long-term (>2 years), however, they have been found to be biologically effective in some cases (Roni et al. 2008). Knowledge gaps are highlighted in Cocchiglia et al. (2012).

The objective of this study was to quantify the short-term (0–2 years) impacts of culvert style replacement following current USFS BMPs of the Klamath National Forest (KNF) of Northern California on the benthic-macroinvertebrate communities of 6 streams. The a priori hypothesis was that benthic macroinvertebrates would show evidence of an impact, which might present itself in the form of increased seasonal and/or annual variability (Resh et al. 2013), and that the effects would be stronger downstream of the culverts than upstream because this is where increased sedimentation would most likely occur as a result of construction activities and the consequent geomorphic responses. This study can be very important for Northern California, the United States, and elsewhere, because similar situations can also exist in other regions, particularly in developing countries with current and/or future culvert projects in montane areas.

Methods

Site description

Six streams in the KNF that were prioritized by the USFS for culvert style replacement were selected for physical, chemical, and biological assessment; throughout the paper, specific stream sites are identified by a 3 letter code (Table 1 and Fig. 1). The USFS prioritized these sites because of their potential as migration barriers for aquatic fauna and their risk of catastrophic failure during high-flow events or debris flows, as suggested by a stream blocking index (USFS 1999). The lithology underlying the sites includes rocks with high erosion potential, such as sandstones, slaty mudstones, siltstones, and shales (Amaranthus et al. 1985). The sites all contained steel-pipe culverts ranging from 2.1 to 3.7 m in diameter and 13–31 m in length that were replaced with open-arched structures (Table 1 and Fig. 2). Prior to reconstruction, the drop from the downstream end of the culverts to the streambed (i.e., a metric of the potential migration barrier) ranged from 1.0 to 2.8 m (Table 1). The study sites are located in the Klamath-Siskiyou ecoregion, which is a biodiversity hotspot with a high number of endemic species, and the microclimates in this region are recognized to be important ecological refuges for anticipated climate change (Olson et al. 2012). In addition to the deleterious effects of roads in the Klamath basin, the freshwater ecosystems are under threat from wildfire (O'Laughlin 2005), hypereutrophication (Eilers et al. 2004), and cattle grazing (Roche et al. 2013).

Crossings at all 6 streams were originally scheduled to be reconstructed during 2004, but as a result of construction delays only