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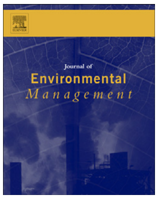

Research article

Riparian vegetation as an indicator of riparian condition: Detecting departures from historic condition across the North American West

William W. Macfarlane [a, *], Jordan T. Gilbert [a], Martha L. Jensen [a], Joshua D. Gilbert [a], Nate Hough-Snee [a], Peter A. McHugh [a, b], Joseph M. Wheaton [a, c], Stephen N. Bennett [a, b, c]

[a] *Department of Watershed Sciences, Utah State University, 5210 Old Main Hill, Logan, UT 84322-5210, USA*
[b] *Eco Logical Research, Inc., Providence, UT 84332, USA*
[c] *Anabranch Solutions, LLC, Nibley, UT 84327, USA*

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ABSTRACT

Floodplain riparian ecosystems support unique vegetation communities and high biodiversity relative to terrestrial landscapes. Accordingly, estimating riparian ecosystem health across landscapes is critical for sustainable river management. However, methods that identify local riparian vegetation condition, an effective proxy for riparian health, have not been applied across broad, regional extents. Here we present an index to assess reach-scale (500 m segment) riparian vegetation condition across entire drainage networks within large, physiographically-diverse regions. We estimated riparian vegetation condition for 53,250 km of perennial streams and rivers, 25,685 km in Utah, and 27,565 km in twelve watersheds of the interior Columbia River Basin (CRB), USA. We used nationally available, existing land cover classification derived from 30 m Landsat imagery (LANDFIRE EVT) and a modeled estimate of pre-European settlement land cover (LANDFIRE BpS). The index characterizes riparian vegetation condition as the ratio of existing native riparian vegetation cover to pre-European settlement riparian vegetation cover at a given reach. Roughly 62% of Utah and 48% of CRB watersheds showed significant (>33%) to large (>66%) departure from historic condition. Riparian vegetation change was predominantly caused by human land-use impacts (development and agriculture), or vegetation change (native riparian to invasive or upland vegetation types) that likely resulted from flow and disturbance regime alteration. Through comparisons to ground-based classification results, we estimate the existing vegetation component of the index to be 85% accurate. Our assessments yielded riparian condition maps that will help resource managers better prioritize sites and treatments for reach-scale conservation and restoration activities.

1. Introduction

In semi-arid and arid environments floodplain riparian ecosystems are often the dominant wetland elements in otherwise dry landscapes (Knopf et al., 1988), providing diverse habitats and ecosystems services. Floodplain riparian ecosystems support disproportionately diverse plant and animal communities relative to adjacent upland ecosystems, with many species occurring only at high abundance in riparian areas (Johnson et al., 1977; Knopf, 1985; Soderquist and Mac Nally, 2000). Flood dynamics and the colonization and stabilization of landforms during vegetation succession create diverse floodplain mosaics (Kleindl et al., 2015) and complex instream habitat (Hupp and Osterkamp, 1996; Kauffman et al., 1997) that support fish and other aquatic biota. Across the interior western U.S. however, many riparian areas have been altered or are threatened by human impacts that directly and indirectly impact stream hydrologic, geomorphic, and ecological processes that shape riparian vegetation (Nilsson and Berggren, 2000; Obedzinski et al., 2001).

Common impacts to riparian vegetation often include flow alteration (Poff et al., 2011) from water withdrawal, diversion or impoundment (Goodwin et al., 1997), intensive agriculture (Allan, 2004; Klemas, 2014), urbanization (Allan, 2004; Hardison et al., 2009; Paul and Meyer, 2001), fire suppression (Stone et al., 2010), invasive plant species (Shafroth et al., 2002; Stromberg et al., 2007),

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* Corresponding author.
E-mail addresses: wally.macfarlane@usu.edu (W.W. Macfarlane), jtgilbert89@gmail.com (J.T. Gilbert), martaljensen@gmail.com (M.L. Jensen), joshuadgilby@gmail.com (J.D. Gilbert), nate@natehough-snee.org (N. Hough-Snee), peter.a.mchugh@gmail.com (P.A. McHugh), joe.wheaton@usu.edu (J.M. Wheaton), bennett.ecological@gmail.com (S.N. Bennett).

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beaver removal (Naiman et al., 1986), and upland species encroachment (Marlow et al., 2006). One result of human disturbance is that as flow regimes and sediment supply are altered, floodplains often become hydrologically disconnected from their channels through channel narrowing or floodplain aggradation (Pollock et al., 2014; Schumm, 1999; Simon and Rinaldi, 2006). As floodplains and channels are decoupled, riparian plant performance declines, reducing many riparian species' competitive abilities (Scott et al., 2000).

On many floodplains, the encroachment of woody invasive species (e.g. *Tamarix* spp., *Elaeagnus angustifolia*) or upland shrubs (e.g. *Juniperus* spp., *Pinus* spp.) serves as a prominent indicator of riparian habitat degradation (Harms and Hiebert, 2006; Jarnevich et al., 2011; Wang et al., 2013). Hydrologic alteration that reduces the magnitude, duration and frequency of floods, for example, often precedes the expansion of *Tamarix* along floodplains (Dean and Schmidt, 2011; Manners et al., 2014). Reduced flows and increased *Tamarisk* abundance reduce native species' physiological performance, shifting community composition further toward *Tamarisk* (Dean and Schmidt, 2011; Manners et al., 2014). When native riparian vegetation is replaced by invasive, woody species, bare, alluvial floodplain landforms can become dense thickets that rapidly accrete sediment, reducing floodplain landforms' inundation frequency and hydrologic connectivity to the channel (Dean and Schmidt, 2011; Manners et al., 2014). When mapped, these invasions manifest themselves as an increase in woody vegetation cover over historic levels (Webb and Leake, 2006). Across the interior western U.S., upland or woody invasive species' dominance is often associated with impaired flow and sediment regimes that limit native vegetation dispersal, establishment, growth and competition, reducing the amount of available native, riparian habitat (Richardson et al., 2005).

Despite widespread study of the causes and consequences of transitions from native riparian vegetation to upland or invasive species (Richardson et al., 2007), and the large number of vegetation change detection methodologies and techniques, utilizing remotely sensed data (Hussain et al., 2013), regional assessments of the magnitude and extent of riparian degradation are rare across western North America. We attribute this largely to a lack of historic data and to methodological limitations (Dunford et al., 2009; Pert et al., 2010). While researchers have used geographic information systems (GIS) to map riparian buffers (Aguiar and Ferreira, 2005; Apan et al., 2002; Pert et al., 2010), vegetation change (Piegay et al., 2009), and condition (Johansen et al., 2008), most of this research has relied on manual aerial photo interpretation or field visits at limited spatial extents (Goetz, 2006). For example, Dunford et al. (2009) mapped 174 ha of the Drone River in France, while Lawson et al. (2007) quantified vegetation change within a single Australian catchment. To understand current ecological and physical conditions and prioritize floodplains for conservation and restoration, Stella et al. (2013) noted that, "… we need to enlarge the scope of riparian studies beyond the site and reach to a true biogeographical perspective of the corridor, catchment, and regional scales."

Recent advancements in image analysis software, imagery resolution, and the availability of accurate, free GIS data, now provide opportunities to map changes in riparian vegetation composition, structure, and spatial extent at unprecedented scales (Dufour et al., 2012). These geospatial tools have evolved in parallel with similar tools for mapping geomorphic change (Wheaton et al., 2010) and mapping landforms (Gilvear and Bryant, 2016), allowing for network scale evaluation and characterization of entire stream networks, including their valley bottoms (Gilbert et al., 2016; Roux et al., 2015). These technical advances allow for unprecedented evaluation of hydrologic, geomorphic, and ecological change of entire river systems. Here, we take advantage of these advances to expand the scope of riparian condition studies to large landscapes where human land- and water-use have altered the hydrologic, physical, and ecological processes that historically supported native riparian vegetation communities. We ask two questions:

(1) *How does current riparian vegetation composition differ from historic riparian vegetation composition across the western United States?*
(2) *Where riparian vegetation has changed from its historic composition, what are the causes of this transition?*

We address these questions by assessing riparian vegetation change (departure from historic condition) across the state of Utah and within twelve watersheds of the interior Columbia River Basin (CRB). We estimate the causes of vegetation change within discrete reaches, mapped to entire drainage networks, and validate current vegetation condition using field observations. These maps of vegetation change, and its probable causes, are presented at a spatial resolution that can support both reach-level assessments of current condition and watershed-scale restoration planning.

2. Methods

2.1. Riparian vegetation departure index

The *riparian vegetation departure index* (RVD) is a ratio that is similar to the 'observed' to 'expected' ('O/E') type metrics used in environmental condition assessments (e.g., Hawkins et al., 2010). RVD characterizes riparian vegetation condition for a given stream reach as the ratio of existing vegetation to an estimation of pre-European settlement vegetation coverage (Fig. 1). To numerically calculate condition, native riparian vegetation is coded as '1' and invasive and upland classes are coded as '0' in both the existing, and pre-European settlement vegetation rasters (see supplementary materials Table S1) and condition is calculated as the ratio of current to historic native riparian coverage for a given reach.

To support reach-level assessments, we bound the lateral extent of our analysis by generating analysis polygons within the valley bottom. By definition, a valley bottom is comprised of the stream or river channel and the associated low-lying, contemporary floodplain (Fryirs et al., 2015; Wheaton et al., 2015). The valley bottom is used because it roughly represents the maximum possible extent of riparian vegetation (Ilhardt et al., 2000). Analysis polygons are generated in three steps. First, each valley bottom unit is split into a series of Thiessen polygons, with centroids located at the midpoint of each stream segment (Fig. 1). Thiessen polygons were chosen for this process because their geometric properties guarantee that all points within a polygon are closer to its centroid than to any other polygons (Esri, 2016). This ensures that vegetation adjacent to the reach is applied to the correct segment, even when working with irregular planform geometries and valley bottoms. This is similar to the concept of Notebaert and Piegay (2013) of breaking up the valley bottom into *discrete geographic objects* (DGOs) using the Fluvial Corridor Tool (Roux et al., 2015). Second, the valley bottom is buffered by the pixel resolution of the vegetation data (i.e., 30-m vegetation data is buffered by 30 m) to ensure that the relevant vegetation data is completely contained within the valley bottom in headwater reaches (Fig. 1). Finally, we clip the Thiessen polygon layer to the buffered valley bottom. The resulting polygons become the analysis features for which the RVD tool calculations are summarized (Fig. 1 and see supplementary materials Fig. S1).

Within each polygon, the mean of the values (i.e. the 1s and 0s) is calculated for both the existing and historic vegetation layers, resulting in values that represent the proportion of each polygon

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