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Vegetation recruitment in an enhanced floodplain: Ancillary benefits of salmonid habitat enhancement

Kirsten L. Sellheim[a,*], Mehrey Vaghti[b], Joseph E. Merz[a]

[a] Cramer Fish Sciences, 3300 Industrial Blvd., Suite 100, West Sacramento, CA 95691, USA
[b] P.O. Box 553, Auburn, CA 95604, USA

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ABSTRACT

Widespread loss and degradation of riverine habitats due to dams, diversions, levees, and human development have led to an increase in river habitat enhancement projects in recent decades. These projects typically focus on improving either terrestrial (e.g., riparian vegetation) or aquatic (e.g., fish spawning and rearing) habitats, and do not commonly address the relationship between the two systems. However, there is abundant evidence that fundamental linkages exist between terrestrial and aquatic ecosystems, and anthropogenic impacts such as urban expansion, agricultural activities, and river impoundment can synergistically degrade both systems. This study examines the effects of adult and juvenile salmonid habitat restoration on recruitment, density, and composition of riparian vegetation in an area heavily impacted by mining and flow regulation. For a year following in-channel coarse sediment placement and floodplain construction in an area previously covered with coarse mine tailings, we compared the abundance, richness and diversity of vegetation across four treatments: the newly constructed floodplain, isolated mine tailings, mine tailings near an access road, and a remnant riparian area that was less impacted by mining. Richness and diversity were higher in the floodplain than in any of the other treatments; we identified a total of 15 plant families in the floodplain treatments, as compared to three to five families in the other treatments. We observed significant differences in plant assemblage composition between treatments, with higher richness of primarily obligate or facultative wetland plant taxa in the floodplain treatment. This study demonstrates that restoring hydrological linkages between aquatic and terrestrial habitats, and redistribution of sediment size classes altered by mining, can create conditions that promote rapid wetland plant colonization, enhancing biodiversity and improving ecosystem function.

1. Introduction

River floodplains provide valuable ecosystem services including habitat for plants, fish and wildlife, groundwater recharge, flood protection and enhanced biodiversity (Sparks, 1995; Ward et al., 1999; Tockner et al., 2010). Floodplain habitats can support high primary and secondary production and provide a trophic link between river ecosystems and adjacent riparian habitats (Bayley, 1995; Ward, 1998; Tockner et al., 1999; Bolpagni et al., 2013). Floodplain productivity is generally driven by the dynamic interaction of floodplain geomorphology with the timing, magnitude, duration and frequency of river discharge (Power et al., 1995; Bornette et al., 1998; Benke et al., 2000). Riparian habitats such as floodplains are also one of the most threatened habitats in the world; agriculture, urban expansion, flow regulation, and mining have all contributed to their degradation and loss (Richter et al., 2003; Verhoeven et al., 2006).

California's Central Valley river systems were once comprised of vast seasonally inundated floodplains that provided habitat for a diverse flora and fauna uniquely adapted to ephemeral and highly variable flooding resulting from a Mediterranean climate (Vaghti and Greco, 2007). These systems supported vast numbers of Pacific salmon (*Oncorhynchus* spp.) by providing productive spawning riffles and rearing floodplains, and complex migration corridors between marine and freshwater habitats (Jeffres et al., 2008; Busch et al., 2013). Anthropogenic activities such as mining, agriculture, and flood protection resulted in deeply incised and simplified river channels largely disconnected from their historic floodplains (Dietrich et al., 1989; Ligon et al., 1995). Gold mining

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* Corresponding author.

E-mail addresses: kirstens@fishsciences.net, kirsten82@gmail.com (K.L. Sellheim), mgvaghti@gmail.com (M. Vaghti), jmerz@fishsciences.net (J.E. Merz).

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generated massive cobble debris piles and perched and armored floodplains adjacent to river channels, further confining streamflow and preventing recruitment of both upland and wetland vegetation, ultimately blocking juvenile salmon from productive floodplain rearing habitat (Kondolf, 1997; Downs et al., 2011; Sellheim et al., 2015). Unlike fine substrates, coarse sediment, such as cobble and large gravel, is unable to retain moisture or store nutrients, thus constraining recruitment of upland and riparian vegetation and reducing primary productivity. Within the river channel, salmonid spawning gravel was buried under large cobble, limiting fish productivity. These effects are further exacerbated by regulated flow regimes, which dampen the hydrograph, shifting flow timing away from spring seed release period of native early-succession tree species, and inhibit coarse substrate transport (Dietrich et al., 1989; Stella et al., 2006). Such hydrologic and geomorphic alterations have adverse consequences for both terrestrial and aquatic communities, causing local extirpation of plant and animal assemblages adapted to intermittently inundated habitats, increased dominance of upland plant species, and reduced rearing and spawning habitat for fish (Roni et al., 2002; Catford et al., 2011; Helfield et al., 2012).

Although salmonids have become a focal point for river restoration activities in recent decades as populations have become depleted, it is important to recognize that simply engineering salmon spawning and rearing physical habitat does not necessarily address the larger challenge of restoring riparian ecosystem function (Tockner et al., 2010; Bond et al., 2014). Aquatic and terrestrial systems are inextricably linked via physical and biological processes, and numerous studies have documented complex feedback loops between the two systems (Allan, 2004; Minshall and Rugenski, 2006; Wipfli and Baxter, 2010). Riparian vegetation can improve in-stream fish habitat by decreasing erosion and turbidity, providing refuge from predators or high flows in the main channel, and creating a thermal barrier that may reduce water temperature (Fischer et al., 2010; McCormick and Harrison, 2011; Thomson et al., 2012; Wootton, 2012). Vegetation may also increase trophic resources for fish, either directly via terrestrial drift invertebrates or indirectly by providing leaf litter, which can boost production of detritivorous aquatic invertebrate prey (Allan et al., 2003; Kawaguchi et al., 2003; Gillette, 2012). Riparian vegetation also receives trophic inputs from the river; seasonal floods deposit nutrient-rich sediment from upstream areas, and decomposing carcasses of post-spawning salmonids can boost terrestrial primary productivity substantially (Kiernan et al., 2010; Holtgrieve and Schindler, 2011).

To achieve long-term ecosystem rehabilitation, the necessity of terrestrial and aquatic system interactions is generally recognized; however, many restoration efforts continue to focus on either instream habitat or riparian vegetation in isolation (Naiman and Latterell, 2005; Nilsson et al., 2005; Mouton et al., 2012; Thomson et al., 2012). If river restoration projects specifically address the relationship between terrestrial and aquatic habitats, the overall impact on ecosystem function, sustainability, and resilience has the potential to be greatly enhanced. In this study, we examine the effects of a river restoration project in a location that was dramatically altered by historic gold mining operations within a highly regulated stream. The primary project objectives were to (1) enhance channel and floodplain connectivity under the current flow regime; (2) provide long-term main channel habitat features (islands, bars, etc.) and enhance benthic invertebrate production by returning cobble substrate to the main channel; (3) return gravel substrate to the river to improve salmonid spawning and incubation habitat; and (4) support riparian vegetation recruitment by improving hydrologic connectivity and re-exposing fine sediment adjacent to the river.

In this analysis, we ask the following questions:

1) Did floodplain construction designed primarily to improve juvenile salmonid rearing habitat enhance percent vegetative cover, richness, and diversity in the floodplain?
2) Do plant assemblages differ between restored floodplain, mine tailings, and undisturbed riparian areas?
3) Does substrate size have a significant effect on vegetation colonization success and plant assemblages?

The results of this study will help research managers better understand the potential for synergistic benefits derived from restoration projects that explicitly restore connectivity between aquatic and terrestrial systems.

2. Methods

2.1. Study site

The Merced River is located in the California Central Valley (Fig. 1). It flows 233 km from the Sierra Nevada Mountains to its confluence with the San Joaquin River. The Merced River and adjacent riparian habitat have been adversely affected by various anthropogenic impacts, including agricultural and urban development, gold and aggregate mining, flow regulation, diversions, and impoundments (Kondolf et al., 1996; Utz et al., 2012). The river historically provided extensive spawning and rearing habitat for anadromous salmonids, including steelhead trout (*Oncorhynchus mykiss*) and at least two races of Chinook salmon (*Oncorhynchus tshawytscha*); however, since 1906 upstream migration has been limited by Crocker-Huffman Dam, located several kilometers upstream of the study area at river km 84 (Yoshiyama et al., 1998). The average flow in the study area during the salmonid rearing period (January to June) is 23.4 m^3 s and the average dry-season flow (July to December) is 9.4 m^3 s (California Department of Water Resources gage # 42712 streamflow data, between April 1999 and December 2012). Currently, only fall-run Chinook salmon and steelhead trout occur in the Merced River downstream of Crocker-Huffman Dam (lower Merced River), and the Chinook population is augmented by a hatchery located just downstream of the dam.

The study site, hereafter referred to as the Merced River Ranch (MRR), consists of approximately 20.2 ha of mine tailings immediately adjacent to the river channel on both banks (Fig. 1). Similar to other areas along the Merced River, the MRR was historically mined for both gold and aggregate. Large-scale aggregate mining began in the Merced River in the 1940s; older mines excavated sand and gravel directly from the riverbed, leaving behind deep pits within the channel. In addition to extensive tailings piles at the MRR, there are patches of vegetated upland scattered throughout the site. Vehicle traffic on an access road on the north bank of the site has reintroduced fine sediment to the coarse mine tailings adjacent to the road.

The primary goals of this multi-year restoration project were to improve instream salmonid spawning habitat by returning gravel substrate to the river and to create seasonally inundated floodplain salmonid rearing habitat. To meet these goals, tailings piles were first sorted according to size by cobble (>6.4 cm), gravel (6.4–4.0 cm), and fines (<4.0 cm). Cobble and gravel were then placed into the river following the Spawning Habitat Integrated Rehabilitation Approach (SHIRA) to enhance channel features including spawning habitat (Wheaton et al., 2004; Fig. 1). A floodplain was cut into the north bank (hereafter referred to as the North Floodplain) and a floodplain side channel on the south bank (hereafter referred to as the South Side Channel) to create