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Riparian canopy expansion in an urban landscape: Multiple drivers of vegetation change along headwater streams near Sacramento, California

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ABSTRACT

Urbanization is thought to decrease riparian tree canopy cover, but this outcome may vary depending on geographic context. We examined changes in land cover and riparian tree canopy near Sacramento, California, a Mediterranean climate region impacted by agriculture before urbanization. We used aerial imagery to quantify changes in land cover and the area, width, and density of riparian tree canopy between 1937 and 2014 for the 85-km^2 Arcade Creek watershed. While watershed land cover shifted almost entirely from pasture and crops to urban development, riparian forested area increased by 38 percent. The median width of riparian tree canopy more than doubled, and the density along smaller streams increased significantly ($p < 0.0001$). We used multiple data sources to examine potential drivers of these changes. Stream gage data and field observations indicated that the formerly intermittent Arcade Creek stream network receives spatially and temporally variable dry-season flow subsidies from urban runoff, but widespread channel incision may limit the impact of subsidies on riparian vegetation. Accordingly, sampling of riparian woody plants showed few hydrophilic species growing along these streams. Instead we found evidence of native oak regeneration and a high density of escaped horticultural species. The increase in riparian forest cover was thus likely due to changes in vegetation management and species composition from land use conversion, possibly augmented by increased dry-season water availability. The changes in canopy cover we quantified stand in contrast to the accepted pattern of riparian forest decline with urbanization, and are expected to affect ecosystem services.

1. Introduction

Stream corridors play a central role in urban ecological research due to their sensitivity to land cover change, as well as their importance for water quality, habitat provision, and urban recreation (Walsh, Roy et al., 2005). Stream ecosystems are influenced by riparian vegetation, and changes in riparian forest cover can have particularly important consequences for small streams due to the large influence tree canopies exert on stream shading and organic matter inputs (Gregory, Swanson, McKee, & Cummins, 1991; Vannote, Minshall, Cummins, Sedell, & Cushing, 1980). Thus, riparian tree canopy loss due to urbanization contributes to altered stream ecosystem function (Paul & Meyer, 2001; Pickett et al., 2011; Wenger et al., 2009). This impact is considered widespread enough to be included in the "urban stream syndrome," a suite of symptoms found to consistently plague urban waterways even when they have not been buried, channelized, or armored. Other symptoms of the urban stream syndrome include flashier hydrographs, elevated concentrations of nutrients and pollutants, altered channel characteristics, and reduced biotic richness (Walsh, Roy, et al., 2005).

While these recognized patterns contribute to our understanding and management of urban streams, it is important to extend our knowledge of how symptoms of the urban stream syndrome may vary depending on geographic context (Booth, Roy, Smith, & Capps, 2016; Hale, Scoggins, Smucker, & Suchy, 2016; Walsh, Roy et al., 2005). Those symptoms related to riparian tree canopy particularly warrant further examination because much of the research informing our understanding of urban streams has been carried out in forested biomes where urban development logically reduces tree canopy. When dense riparian forest is not the initial condition, though, the impacts of development need to be reconsidered. For example, in more arid parts of the American West, riparian forest cover along smaller streams is often patchy or narrow (Miller, Wiens, Hobbs, & Theobald, 2003; Saab, 1999), and may have been significantly degraded or reduced by mining, grazing, and other agricultural activities prior to urbanization (Patten, 1998). Urbanization in such systems may augment dry-weather stream flows with inputs from landscape irrigation, leaking water infrastructure, and wastewater treatment plants, which can create perennial flows in channels that were once seasonally dry (Stein & Ackerman,

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2007; Townsend-Small et al., 2013; Villarreal, Drake, Marsh, & Mccoy, 2012; White & Greer, 2006). This increase in stream flow has been linked to the expansion of riparian tree canopy (Villarreal et al., 2012; White & Greer, 2006).

In California's Mediterranean climate, many headwater streams were historically intermittent, with relatively sparse tree canopies (Gasith & Resh, 1999; Grossinger, Striplen, Askevold, Brewster, & Beller, 2007). Further, much of the state was heavily impacted by agriculture prior to urban expansion. In particular, California's Central Valley was almost entirely converted to agricultural production in the latter half of the 19th century, and riparian trees were cut to make way for field crops and orchards, as well as for fuel and building materials (Cunningham, 2010; Katibah, 1984). Some areas were also used for cattle grazing (Harris & Allee, 1963), which can inhibit woody regeneration along streams (Belsky, Matzke, & Uselman, 1999; Kauffman & Krueger, 1984). Since urbanization in this context represents a release from agricultural pressures, with most buildings set back from streams due to flooding concerns, it could provide the opportunity for woody riparian vegetation to re-establish without intervention (Batchelor, Ripple, Wilson, & Painter, 2015; Rickard & Cushing, 1982). In addition, urban riparian zones may be planted intentionally with woody species for aesthetic, recreational, and ecological benefits (Riley, 2016), while in unmanaged areas, escaped exotic shrubs and trees can increase riparian canopy density above historical levels (Miller et al., 2003). These factors suggest the potential for forest gain, rather than loss, along urban streams in California's Central Valley.

This study characterizes historical changes in riparian tree canopy over eight decades in relation to urbanization in a Central Valley watershed, located in the metropolitan area of Sacramento, California. We used digital methods to analyze coarse- and fine-scale change in the extent of riparian tree canopy along the entire stream network, and investigated potential drivers of change by 1) quantifying changes in land cover across the watershed through the use of aerial photography, 2) characterizing historical and current stream flows from stream gage data and field observations, and 3) evaluating the contribution of exotic species to riparian tree stem density via field sampling throughout the stream network. We hypothesized that urban development would result in an overall increase in riparian tree canopy, and that increases would be greatest along the smallest streams due to sparser initial canopy cover. The use of multiple data collection approaches allowed us to evaluate changes in riparian canopy across the entire watershed while gaining cross-scalar insight into factors that might contribute to these changes.

2. Methods

2.1. Site description

Sacramento, California, is a rapidly urbanizing area in California's Central Valley. The population of Sacramento County, which is currently around 1.4 million, has more than doubled since 1980, and is projected to increase by an additional 35 percent by 2036 (Sacramento Area Council of Governments, 2016). Sacramento has a Mediterranean climate, with cool, wet winters, and hot, dry summers. Mean annual rainfall since 1941 is 43.8 cm, with the majority falling between October and April; only trace amounts fall in summer. The January mean minimum temperature is 3.2 °C, and July mean maximum temperature is 33.7 °C (WRCC, 2016). The area has deep alluvial soils and low water tables, with the depth to groundwater exceeding 30 m in many areas (Criss & Davisson, 1996). Historical vegetation in the area was likely dominated by open grasslands and woodlands, with denser forests concentrated in the floodplains of the major rivers (CSU Chico, 2003; Katibah, 1984).

Our study was conducted in the Arcade Creek watershed, which encompasses a large portion of the northeastern Sacramento metropolitan area (Fig. 1) and is the only small watershed in this vicinity with a United States Geological Survey (USGS) streamgage station. Current land use in the watershed is primarily residential, with typical housing densities of between 6 and 12 single-family residences per hectare. Impervious surfaces cover around 45% of the watershed area (MRLC, 2014). We delineated the 85-km^2 watershed with the ArcHydro extension of ArcGIS v10.2 (ESRI, Redlands, California, USA), using a 1/3-arc-second digital elevation model from the USGS National Elevation Dataset. The watershed's topography is relatively flat, with elevations from 10 m at the outflow to 85 m in the headwaters. The stream network currently includes approximately 80 km of streams, with first- and second-order streams (Strahler, 1957) comprising around two-thirds of that length. We assigned the Strahler stream order—a proxy for stream size, with smaller streams assigned lower numbers—for each stream segment in the watershed, based on USGS topographic maps from 1902 and 1911. These maps show the entire stream network as intermittent or ephemeral. While there is very little specific information on the historical vegetation in the watershed, it was likely primarily oak woodland, with some grassland areas nearer to the mouth of the stream (CSU Chico, 2003). Beginning in the mid-1800s, the watershed was largely cleared for agriculture.

2.2. Aerial imagery and land cover mapping

We used high-resolution aerial imagery to analyze changes in riparian tree canopy and land cover. We acquired 2014 digital orthoimagery of the Arcade Creek watershed area from the United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP), which has a 1-m resolution, and 1937 and 1984 black-and-white aerial print photographs of the same area from the UC Davis Library. The 1937 photographs were taken at a scale of 1:20,000, and the 1984 photographs at a scale of 1:31,680. The large time gap between the two sets of print photographs is due to a lack of suitable intermediate imagery. We projected the NAIP imagery using the NAD 83 California (Teale) Albers projection. The historical aerial photographs were scanned and georeferenced to the 2014 NAIP imagery using control points to match consistent features such as buildings, road intersections, bridges, and topographic features present in both images. We used a projective transformation with a minimum of 10 control points per photograph, and allowed a maximum overall root mean square error (RMSE) of 5 m for each scanned image. For the total project, we achieved a mean RMSE of 2.45 m with an average of 19 control points per photograph. Georeferenced images from each time period were then mosaicked to form seamless rasters that encompassed the entire watershed area.

Based on the aerial imagery, we digitized land cover for each time period using five categories: developed land, irrigated crops, un-irrigated herbaceous vegetation, bare ground, and tree canopy. Developed land included irrigated open spaces such as golf courses, parks, sports fields, and lawns. Because all aerial imagery was taken in the summer, un-irrigated herbaceous vegetation was generally easy to distinguish from irrigated turf by its brown or light hue. Patches were mapped if they included an area that could encompass a square with 50-m diagonals. If two patches of different land cover were separated by an intervening land cover that was not large enough to be mapped on its own, then the intervening area was divided evenly between the two neighboring patches. The total area of each patch type was calculated from the resulting feature classes in ArcMap.

2.3. Riparian land cover and digital sampling of riparian tree canopy

We used several metrics to examine changes in riparian tree canopy over time. To assess coarse-scale change, we analyzed areal changes in riparian zone land cover. We applied a 50-m buffer to the stream network and calculated the total area of each land cover type within the buffer for each time period. The total change in area of tree canopy in this buffer provided a simple assessment of whether riparian forest