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Riparian trees and aridland streams of the southwestern United States: An assessment of the past, present, and future

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ABSTRACT

Riparian ecosystems are vital components of aridlands within the southwestern United States. Historically, surface flows influenced population dynamics of native riparian trees. Many southwestern streams has been altered by regulation, however, and will be further affected by greenhouse warming. Our analysis of stream gage data revealed that decreases in volume of annual discharge and mean peak discharge and a shift to earlier peak discharge will occur in the Southern Rockies region of Colorado, New Mexico, and Utah. These changes will likely decrease rates of reproduction and survival of cottonwood (*Populus fremontii* and *Populus deltoides* ssp. *wislizenii*), Goodding's willow (*Salix gooddingii*), and boxelder (*Acer negundo*), which rely on surface flows to stimulate germination and recharge groundwater aquifers. Streams in the Central Highlands of Arizona and New Mexico will likely see reductions in annual discharge volume, which could limit reproduction and survival of the above taxa and Arizona sycamore (*Platanus wrightii*). These effects may be exacerbated by demands of expanding urban areas and agricultural operations, but could also be ameliorated by increasing water use efficiency and environmental mitigation. These factors must be considered, along with climate projections, when planning for conservation of riparian trees and the animal communities they support.

1. Introduction

Riparian ecosystems are uncommon and highly-valued components of aridlands in the western United States. Much of this value comes from woody plants that grow along the alluvial reaches of many streams, forming green avenues on the desert landscape. Riparian trees in particular are essential components of wildlife habitat. While living, as standing snags, and as fallen woody debris, these trees provide animals with shade, shelter, and foraging opportunities that are often absent in adjacent plant communities (Carothers et al., 1974; Bock and Bock, 1984; Brown, 2002; Smith et al., 2012; Smith and Finch, 2014). For centuries southwestern streams and their riparian trees have been favored by human communities as sources of material goods and for their aesthetic value (Bock and Bock, 1989; Weber and Stewart, 2009).

Hydrological patterns have deviated substantially from historical conditions at many streams in the southwestern United States. Changes have occurred in large part due to regulation of streams for agricultural, industrial, and municipal purposes. Water has been diverted in the Southwest since the establishment of pre-Columbian societies, but changes accelerated during the 20th century when demand for irrigation and municipal water increased with the rapid expansion of agricultural and urban areas (Phillips et al., 2011; Summitt, 2013). To meet these demands, federal agencies and local irrigation districts conducted a series of large-scale water projects from the early 1900s to the 1970s. These projects included the construction of increasingly large dams and reservoirs and transbasin diversions. Because of these projects, discharge is now reduced from historical levels at many streams and some sections that once had perennial flows now run dry, apart from periods of heavy runoff (White and Stromberg, 2009). Other sections are inundated by dams while, below dams, magnitude and timing of peak discharges are altered when releases are scheduled for irrigation and power generation (Finch et al., 2014).

Southwestern streams and their riparian ecosystems are also vulnerable to alterations resulting from anthropogenic climate change, the effects of which are expected to be especially severe in the American Southwest (Seager et al., 2007; Garfin et al., 2014). Climatologists predict that, under current and projected levels of CO_2 emissions, higher temperatures and smaller snowpacks will

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reduce the amount of runoff that enters streams (Pierce et al., 2008; Seager and Vecchi, 2010; Seager et al., 2013). Droughts, which have been a regular feature in recent years, will continue to occur, but with increasing severity, resulting in further reductions in discharge volume (Cayan et al., 2010; Woodhouse et al., 2010; Gutzler and Robbins, 2011). Summer monsoons also cause flood events in many of the region's streams (Stromberg et al., 2010). Changes in patterns of these storms are more difficult to model than other types of precipitation, but there is evidence that greenhouse warming will force monsoons to occur later in the year and with greater severity, further changing stream dynamics (Cook and Seager, 2013; Serrat-Capdevila et al., 2013). These projected changes will undoubtedly affect riparian ecosystems by limiting germination and increasing mortality of species dependent on floods and groundwater, to the benefit of generalist species, including nonnative trees and shrubs (Stromberg et al., 2010; Perry et al., 2012).

Current and projected hydrological patterns are not uniform among southwestern streams (Dixon et al., 2009), and an understanding of this variation is needed to forecast the effects of climate change on riparian trees. Sources of runoff vary from snowfields in the Southern Rockies to rain in the mountains near the U.S.-Mexico border to combinations of snow and rain in the areas between (Blakemore et al., 1994). Surface flow and groundwater dynamics are also influenced by variables including geology, climate, and extent of regulation (Merritt and Poff, 2010). Consequences of future changes in temperature and precipitation will therefore vary across the American Southwest (Dixon et al., 2009; Perry et al., 2012). In addition to response of streams to climate change, response of woody species will likely vary as well, given their differing requirements for reproduction, growth, and survival. Woody riparian plants also vary in their ecological relationships to other plants and animals. Climate change effects on riparian ecosystems may therefore be affected by interactions between floristic and hydrological characteristics.

Streams in the Colorado River and Rio Grande basins have been extensively studied for over a century, first to develop an understanding of hydrological patterns, which was essential to the development of infrastructure, and later to understand the ecological consequences of regulation (Phillips et al., 2011). Hydrological projections have also been made for many of these streams to help water users plan for future needs in a changing climate (Miller et al., 2011). By combining these sources of information, we (1) describe characteristics of surface flows measured at stream gage sites distributed across the southwestern U.S., (2) compare projected changes in these characteristics, (3) review hydrological requirements and ecological function of four taxa of riparian trees, and (4) discuss the likely effects of hydrological change on aridland riparian forests. This information can be used to prioritize research and management actions necessary to protect imperiled riparian species and their habitats.

2. Methods

2.1. Stream sites

We compiled information for 11 stream gage sites in the Colorado River and Rio Grande basins (Supplemental map). We chose gage sites that were located on alluvial reaches with woody vegetation. At each site, measurable surface flows occur during most months of the year, at least 40 years of hydrological data have been recorded by the U.S. Geological Survey (USGS), and future discharge patterns have been modeled by the U.S. Bureau of Reclamation (USBOR). For the purposes of this analysis, we classified the streams into two geographical groups. Six of the streams, referred to hereafter as Southern Rockies streams, are headwatered in the Rocky Mountains of Wyoming and Colorado. Five streams, referred to as Central Highland streams, are headwatered in the Central Highland ranges of Arizona and New Mexico. The Southern Rockies stream sites are on the Colorado River, the Green River, the Gunnison River, the San Juan River, the Rio Chama, and the Rio Grande. The Central Highland stream sites are on the Gila River, the Salt River, the San Francisco River, Tonto Creek, and the Verde River. Gage sites are between 600 and 2000 m in elevation, and are located in the states of Arizona, Colorado, New Mexico, and Utah (Table 1).

2.2. Tree species

We visited stream gage sites and reviewed published information to describe the distribution and biology of four native tree taxa that are important components of aridland riparian ecosystems and whose reproduction and survival are closely tied to surface flows (Fig. 1). Two superficially similar cottonwood tree species: Fremont cottonwood (*Populus fremontii*) and Rio Grande cottonwood (*Populus deltoides* ssp. *wislizenii*), are referred to hereafter as cottonwood. The remaining taxa are Goodding's willow (*Salix gooddingii*), boxelder (*Acer negundo*), and Arizona sycamore (*Platanus wrightii*). These taxa are distributed across several southwestern stream systems and have been identified by multiple sources as important components of riparian wildlife habitat. We obtained information about the distribution of each species from the Global Biodiversity Information Facility website (www.gbif.org). We reviewed peer-reviewed publications to summarize hydrological effects on their reproduction, survival, and use by animal communities.

2.3. Hydrological analyses

We analyzed historical and projected patterns of hydrological variables that affect survival and reproduction of riparian trees. These variables, defined here, were *annual discharge* (in million cubic meters): the total volume of water measured at a stream gage site each year; *mean daily discharge* (in cubic meters per second): the mean discharge volume for each day of the year; *peak discharge volume* (in cubic meters per second): the maximum mean daily discharge value recorded each year; and *peak discharge date* (in water year ordinal date): the day of each year when the peak discharge occurred. We selected these variables because large fluctuations in annual discharge and mean daily discharge affect survival of riparian trees through drought and flood mortality. In addition, peak discharge magnitude and date determine whether or not riparian trees will successfully reproduce during a given year (Lytle and Merritt, 2004).

We obtained mean daily discharge data for the longest complete historical period (no gaps in data exceeding 1 month) ending in 2013 at each of the 11 stream gage sites (Table 1). Data were collected by USGS and made available online by the National Water Information System Database (http://waterdata.usgs.gov/nwis). We calculated the total annual discharge for each site for each year of its historical period. To describe characteristics of peak discharges, we determined peak discharge volume and date for each year of the historical period as well. We calculated the mean, maximum, and coefficient of variation (CV) across years for annual discharge and peak discharge volume. We also calculated the mean and CV of peak discharge date across years.

We tested for trends in annual discharge, peak discharge volume, and peak discharge date using the Mann-Kendall statistic. This nonparametric, rank-based test has used to detect positive or negative trends in hydrologic time series data in numerous studies because it does not assume normality and is robust to missing