Journal of Arid Environments 134 (2016) 104–121

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Climate, streamflow, and legacy effects on growth of riparian *Populus angustifolia* in the arid San Luis Valley, Colorado

Douglas C. Andersen

U.S. Geological Survey, Fort Collins Science Center, 2150 Centre Avenue, Building C, Fort Collins, CO 80526-8118, USA

ARTICLE INFO

Article history:
Received 12 December 2015
Received in revised form
13 April 2016
Accepted 18 July 2016

Keywords:
Climate variation
Ephemeral stream
Groundwater
Narrowleaf cottonwood
Palmer Drought Severity Index
Tree rings

ABSTRACT

Knowledge of the factors affecting the vigor of desert riparian trees is important for their conservation and management. I used multiple regression to assess effects of streamflow and climate (12–14 years of data) or climate alone (up to 60 years of data) on radial growth of clonal narrowleaf cottonwood (*Populus angustifolia*), a foundation species in the arid, Closed Basin portion of the San Luis Valley, Colorado. I collected increment cores from trees (14–90 cm DBH) at four sites along each of Sand and Deadman creeks (total $N = 85$), including both perennial and ephemeral reaches. Analyses on trees <110 m from the stream channel explained 33–64% of the variation in standardized growth index (SGI) over the period having discharge measurements. Only 3 of 7 models included a streamflow variable; inclusion of prior-year conditions was common. Models for trees farther from the channel or over a deep water table explained 23–71% of SGI variability, and 4 of 5 contained a streamflow variable. Analyses using solely climate variables over longer time periods explained 17–85% of SGI variability, and 10 of 12 included a variable indexing summer precipitation. Three large, abrupt shifts in recent decades from wet to dry conditions (indexed by a seasonal Palmer Drought Severity Index) coincided with dramatically reduced radial growth. Each shift was presumably associated with branch dieback that produced a legacy effect apparent in many SGI series: uncharacteristically low SGI in the year following the shift. My results suggest trees in locations distant from the active channel rely on the regional shallow unconfined aquifer, summer rainfall, or both to meet water demands. The landscape-level differences in the water supplies sustaining these trees imply variable effects from shifts in winter-versus monsoon-related precipitation, and from climate change versus streamflow or groundwater management.

Published by Elsevier Ltd.

1. Introduction

Riparian plant communities are key contributors to local and regional biodiversity, particularly in arid and semiarid regions (drylands) where their physiognomic heterogeneity and high productivity support unique arrays of consumer, detritivore, and decomposer organisms (Levick et al., 2008; Soykan et al., 2012). The nature of dryland riparian plant communities, in turn, is strongly dependent on local streamflow and groundwater conditions (Stromberg and Merritt, 2015). This dependency makes these communities vulnerable to disruption by water resource management activities and has resulted in dramatic declines in desert riparian habitat extent and quality, both in the western United States (Andersen et al., 2007; Obedzinski et al., 2001) and globally (Tockner and Stanford, 2002). In the drylands of the western U.S., the precipitation decline predicted to accompany climate change (Perry et al., 2012) is likely to further alter riparian communities as local hydrologic regimes respond to shifts in catchment water budgets. These vulnerabilities have prompted research to acquire the knowledge and develop the tools for long-term management of remaining dryland riparian plant communities. These efforts rely on understanding how species respond to fluvial-geomorphic, hydrological, and other environmental conditions (Rood et al., 2005; Shafroth et al., 2010).

Dryland riparian woodlands in North America commonly contain tree species from the genus *Populus*, i.e., a cottonwood or poplar. These trees serve as foundation species, defining floodplain forest structure and controlling ecosystem dynamics (Ellison et al., 2005). Although much is known about the autecology of some *Populus* species, narrowleaf cottonwood (*Populus angustifolia* James) has received relatively little attention despite its distribution in Rocky Mountain riparian habitats from southern Canada to northern Mexico (Argus et al., 2010). Dryland narrowleaf

E-mail address: doug_andersen@usgs.gov.

http://dx.doi.org/10.1016/j.jaridenv.2016.07.005
0140-1963/Published by Elsevier Ltd.

cottonwoods are obligate phreatophytes, with a root system generally confined to the soil's upper few meters (Pregitzer and Friend, 1996; Rood et al., 2011), making shallow groundwater during the growing season a necessary condition for population persistence. The species is dioecious and wind-pollinated, producing small, short-lived seeds dispersed by wind and water. However, individuals also readily expand clonally through production of root sprouts (Braatne et al., 1996; Gom and Rood, 1999). Plants are relatively tolerant of physical disturbance, including flooding. These traits contribute to narrowleaf cottonwood commonly serving as a pioneer species on floodplains.

Narrowleaf cottonwood is the only tree present in the northern portion of the San Luis Valley (SLV), a large (8300 km^2), high altitude (2300 m) cold-desert basin in south-central Colorado. The trees form discontinuous bands along perennial and ephemeral stream channels that carry runoff from the adjacent Sangre de Cristo Mountains through federally owned and protected lands within Great Sand Dunes National Park and Preserve and neighboring Baca National Wildlife Refuge. In the early 2000s, biologists noted branch dieback in many of these trees, indicative of past or ongoing physiological stress from drought (Rood et al., 2000) or other factor. A regional drought had indeed begun in 1999 (Henz et al., 2004), but another potential source of stress was groundwater pumping near the park and refuge boundaries. The pumping had begun in the mid-1980s when the federal Closed Basin Project began extracting $>10^6$ m^3 of shallow groundwater annually from the SLV for delivery to the Rio Grande for downstream use (Reclamation, 2003).

Annual growth in mature dryland riparian *Populus* can be strongly correlated with factors affecting the water table and plant-available soil water (Andersen, 2016; Edmondson et al., 2014; Meko et al., 2015). Further, severe water stress can cause crown dieback (Rood et al., 2000) and is associated with greatly restricted radial growth (Scott et al., 1999, 2000). Thus, interannual variation in radial growth provides a means to assess a tree's history of exposure to water stress. Confounding the relationship, however, is the fact that dieback—a permanent loss of a portion of the tree's canopy—might produce at least a short-term legacy of restricted growth, even if environmental conditions are highly favorable, until lost primary production is replaced through canopy expansion and restoration of former leaf area.

Here I add to the autecological knowledge of narrowleaf cottonwood and assess the potential causes of dieback in the northern SLV by testing the hypothesis that interannual variation in radial growth of adult trees can be largely explained by interannual variability in climate and/or associated stream flow. I compare the factors affecting growth in spatial groups of trees near to and far from the stream channel at multiple sites along two streams in order to gain insight into whether summer precipitation associated with the North American monsoon is an important contributor to growth of SLV cottonwoods. By focusing on how growth is linked to streamflow, water table dynamics, and years having unusual climate conditions during the growing-season, I provide insight into the hydrological mechanisms sustaining these trees and the presence and magnitude of legacy effects. That focus also provides a means to assess the potential adverse effects from the Closed Basin Project through a before-and-after comparison of growth patterns in trees closest to the project's extraction wells.

2. Materials and methods

2.1. Study area

I worked along Sand and Deadman creeks in Great Sand Dunes National Park and Preserve and the Baca National Wildlife Refuge in south-central Colorado (Fig. 1). Both creeks have their headwaters in the ~4000-m high Sangre de Cristo Mountains and flow westward into the Closed Basin portion of the SLV, where their channels terminate in a playa complex (Mayo et al., 2007). Streamflow at the mountain front is probably perennial, whereas flow becomes ephemeral as one moves away from the alluvial fans of the mountain front and onto the “sand sheet” making up much of the valley floor. High infiltration rates in the channel beds (Hadlock et al., 1997; Harte et al., 2007) result in the streamflow-derived riparian water table declining with lateral distance from the channel (Wurster et al., 2003). Depth to the riparian water table also varies spatially due to topographic variation in the riparian zone produced through aeolian and fluvial geomorphic processes.

Both Deadman and Sand creeks feature a snowmelt-driven spring flood pulse. This pulse has been subject to human manipulation in reaches on the sand sheet. Sheep and cattle ranchers, present in the SLV since at least the mid-1800s, diverted flows to flood-irrigate valley floor areas for native grass (hay) production, but the location and frequency of diversions are unknown.

The valley floor climate is arid (mean annual precipitation < 250 mm), whereas the creek headwaters receive more than 1000 mm of precipitation annually, primarily as snow. Winter temperatures < −20 °C and summer temperatures >30 °C

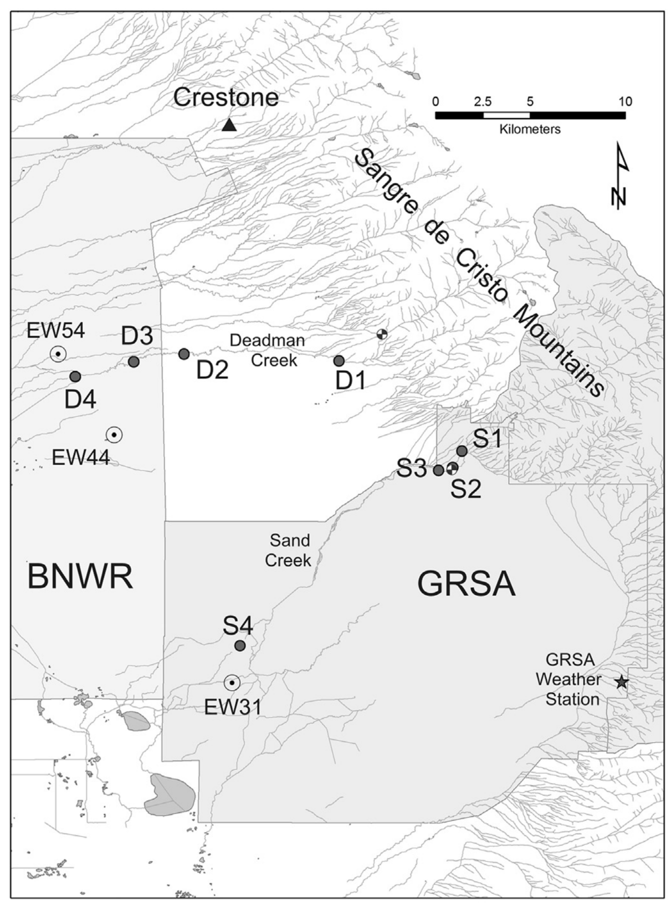

Fig. 1. Map of the study area within the Baca National Wildlife Refuge (BNWR) and Great Sand Dunes National Park (GRSA) and adjacent Preserve, near Crestone, Colorado, showing drainage channels on the west slope of the Sangre de Cristo Mountains and the location of the four study sites along each of Sand and Deadman creeks (S1-S4 and D1-D4, respectively). Stream gauge locations are shown with the quarter-filled circles. The locations of the Closed Basin Project (CBP) monitoring wells (EW31, EW44, and EW54) closest to the study sites are also shown. The closest CBP groundwater extraction wells are located ~4 km west of the map boundary.