

Chapter 3. Impacts of Interacting Fire, Climate, and Hydrologic Changes on Riparian Forest Ecosystems in the Southwest

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Introduction

Changes in human populations, water use, climate, and related disturbances are impacting riparian ecosystems throughout the western United States. Nowhere is this more pronounced than in the arid American Southwest (Gutzler 2013; Molles et al. 1998; Webb et al. 2007). Changes in southwestern riparian ecosystems are often visible to the casual eye in the form of reduced and channelized water along stream courses, loss or changes in riparian vegetation, fire, and urbanization. To manage these changes and improve ecosystem resiliency for the future, a better understanding of the impacts of stressors and disturbances on southwestern riparian ecosystems, and especially on resources of high value from human and ecological perspectives, is needed. We focus on aridland riparian forests in this chapter owing to their values for recreation, wildlife habitat, and energy and nutrient input.

Aridland riparian forests are composed of species in plant guilds that vary in their response to surface flows and groundwater (fig. 3; Stromberg and Merritt 2015).

a)



Figure 3—Examples of southwestern riparian forests: (a) along the Gila River in southwestern New Mexico, with a Fremont cottonwood and Arizona sycamore canopy and Goodding's willow, boxelder, and other woody species in the subcanopy;



Figure 3—Examples continued. (b) near the Verde River in central Arizona with a mesquite bosque (foreground) and cottonwood canopy (upper center);



Figure 3—Examples continued. (c) along the San Juan River in southeastern Utah with Fremont cottonwood, Russian olive, and saltcedar (background), which has been defoliated by leaf beetles;



Figure 3—Examples continued. and (d) along the Middle Rio Grande in central New Mexico with Rio Grande cottonwood, saltcedar, and Russian olive.

Taxa in hydriparian guilds include cottonwoods (*Populus* spp.) and willows (*Salix* spp.). Mesoriparian and xeriparian taxa include boxelder (*Acer negundo*), mesquites (*Prosopis* spp.), and invasive, nonnative species such as Russian olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarix* spp). The extent of riparian forests is small relative to other southwestern plant communities and is largely determined by complex interactions among human activity, climate, and disturbance processes. Fremont cottonwood (*Populus fremontii*), Arizona sycamore (*Platanus wrightii*), and other woody species provide birds and other animals with nesting sites and foraging opportunities that are often absent in upland plant communities (Bock and Bock 1984; Carothers et al. 1974). The structurally diverse, species-rich vegetation along many southwestern streams supports high densities of territories and nest sites for a variety of birds including the Federally endangered southwestern willow flycatcher (*Empidonax traillii extimus*), the threatened western population of yellow-billed cuckoo (*Coccyzus americanus*), and other species of high conservation priority such as Lucy’s warbler (*Oreothlypis luciae*) (Finch et al. 2006; Friggens and Finch 2015; Smith and Finch 2014).

Given the acceleration of human influence at local to global scales and changes in climate, fire severity and frequency, and other stressors, it is critical to assess the effects and interactions of natural and altered disturbance regimes on riparian forest ecosystems and species in the Southwest. Such information will help us understand ecosystem vulnerability and develop actions to manage ecosystems for improved resiliency (Friggens et al. 2013). In this chapter we examine these effects through the lens of native and non-native riparian woody vegetation. The Middle Rio Grande riparian forest, known as the “bosque,” is highlighted as a case study.

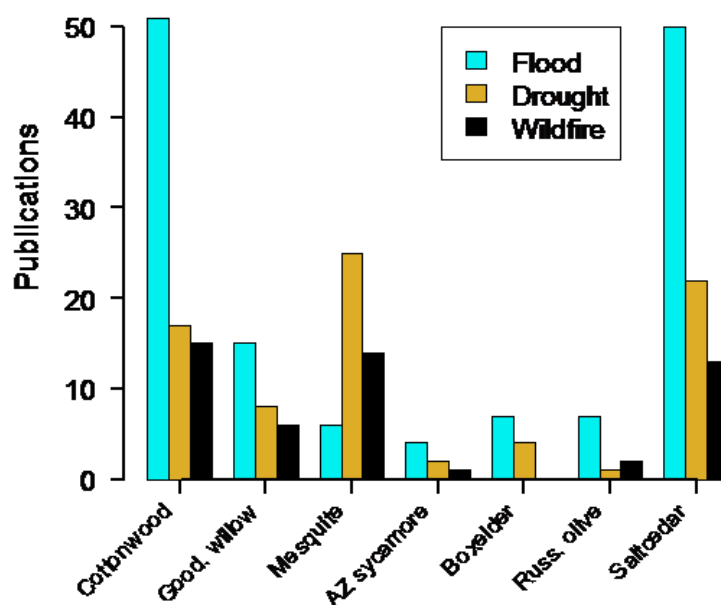
Disturbance and Woody Riparian Vegetation

Flood, drought, and wildfire are primary components of disturbance regimes affecting aridland riparian forests. These disturbances can be caused by natural climate and hydrological cycles, human activity, or their interactions. To evaluate the state of knowledge on these disturbances, we searched for papers describing the response of native and nonnative woody species to flood, drought, and wildfire. We focused on seven taxa common to these forests: Fremont cottonwood and Rio Grande cottonwood (*Populus deltoides* ssp. *wislizenii*), combined hereafter as “cottonwood”; Goodding’s willow (*Salix gooddingii*); velvet mesquite (*Prosopis velutina*) and honey mesquite (*Prosopis glandulosa*), combined hereafter as “mesquite”; Arizona sycamore; boxelder; Russian olive; and saltcedar. We found studies of drought and flood effects by searching for the common and scientific names of each species, along with “flood” and “drought” in the online citation service Web of Science. To find studies of wildfire effects we used the same procedure in Web of Science and expanded our search by using Google Scholar.

Effects of Flooding and Flood Reduction

Flood is the most frequently studied disturbance for all taxa but mesquite (fig. 4). In the Southwest, floods can occur throughout the year, fueled by snowmelt, rain, or a combination of the two. High-magnitude flows occasionally create enough shear stress, erosion, and sedimentation to kill individuals or remove entire stands of shrubs or trees (Bock and Bock 1989; Friedman and Auble 1999; Minkley and Clark 1984). Conversely, floods are in some way instrumental for reproduction of most, if not all woody riparian species. Vegetative reproduction occurs when above- or below-ground portions of woody plants are transported by flood and buried by sediment (Rood et al. 2007). Floods also create opportunities for germination of pioneer species including cottonwood, Goodding’s willow, and Arizona sycamore (Stromberg and Merritt 2015) and produce germination sites by delivering damp sediment and removing litter and competing vegetation (Braatne et al. 1996; Stromberg 1997, 2002). By wetting unsaturated

Figure 4—Number of publications reporting effects of flood, drought, and wildfire on seven woody riparian species in North America. Flood and drought papers were found by searching for common and scientific names with “flood” and “drought” in Web of Science; wildfire papers were found using the same procedure in Web of Science and Google Scholar.



soil layers, flood waters induce germination and support the growth of seedlings until their roots have reached the saturated layer of soil, forming a connection necessary for survival in arid conditions (Bhattacharjee et al. 2006; Horton and Clark 2001; Mahoney and Rood 1998).

Boxelder, mesquites, and Russian olive have relatively large, long-lived seeds that can germinate in the presence of litter and competing vegetation. Though their seeds do not require flood-exposed sites, flood-dampened soil is needed for germination, especially if rainfall is insufficient (Katz and Shafroth 2003; Dewine and Cooper 2007; Stromberg 1993). Mesquite seedlings do not survive well in saturated soil, so mesquite bosques often occupy the outer portions of riparian zones, beyond the area occupied by cottonwood, willow, and sycamore (Stromberg 1993). Where surface flows are intermittent, floods are needed to both replenish groundwater aquifers and deliver nutrients to the soil—processes critical to growth and survival of individuals across guilds and age classes (Stromberg 2001a).

At many streams, frequency, magnitude, and timing of floods have been altered by diversions and dams, with well-documented effects on woody riparian plants (Webb et al. 2007). Though cottonwood and willow recruitment often occurs along narrowed streams following dam construction, opportunities for further reproduction are limited by the reduction of flood scour and sediment deposition (Coble and Kolb 2013; Howe and Knopf 1991; Merritt and Poff 2010; Shafroth et al. 2002). Reduction in magnitude of floods can also limit recruitment of mesoriparian and xeroriparian species that grow at higher elevations of the floodplain (Coble and Kolb 2013; Stromberg 1993). In turn, flow modification encourages establishment of Russian olive, which does not require flood-dampened soil or exposed sites for germination (Katz and Shafroth 2003).

Timing of flow events, such as floods and baseflows, influences reproduction of woody species and riparian forest composition (Beauchamp and Stromberg 2007; Birken and Cooper 2006). A shift in timing of peak discharge away from the dispersal period of pioneer species' short-lived seed will prevent their germination (Fenner et al. 1985). Saltcedar has similar requirements for germination as cottonwood, Goodding's willow, and Arizona sycamore, but it has a longer, more variable period of seed release (Stevens and Siemion 2012). Changes in timing of peak discharge, caused by regulation, can therefore encourage replacement of native species by saltcedar.

Drought Effects

The water required by riparian trees for reproduction, growth, and survival is accessed from surface flows, groundwater, and precipitation (Kolb et al. 1997; Snyder and Williams 2000). These water sources are also linked to one another through natural hydrological processes (Webb and Leake 2006). Periodic shortages in these sources occur naturally across climatic cycles, but for over a century shortages have been caused or exacerbated by surface flow diversion, groundwater withdrawal, and reservoir storage (Phillips et al. 2011; Summitt 2013). Studies have examined effects of stream drying, both natural and human-induced, in a variety of native and nonnative taxa, with cottonwood, mesquite, and saltcedar receiving the most attention in the literature (fig. 4).

Cottonwood, Goodding's willow, and Arizona sycamore are hydriplant taxa that can form an extensive forest canopy where groundwater remains accessible to their

shallow roots (Lite and Stromberg 2005; Stromberg 2001b). Of these taxa, Goodding's willow is the most dependent on shallow depth to groundwater and often establishes closest to the stream channel. Mesquite, boxelder, Russian olive, and saltcedar are mesoriparian and xeroriparian taxa that can establish throughout a floodplain (Dewine and Cooper 2008; Stromberg et al. 2007). Mesquites are capable of attaining large size and forming extensive stands known as bosques. For mature mesquite bosques to form, trees must have access to groundwater at depths of 15 m or less, though 6 m or less is ideal (Stromberg 1993).

When depth to groundwater increases, hydroriparian species respond rapidly through reduction of growth, branch dieback, and stem mortality (Coble and Kolb 2012; Stromberg et al. 2007). Mesoriparian and xeroriparian species can therefore gain a competitive advantage over hydroriparian species when moderate drought occurs (Cleverly et al. 1997; Horton et al. 2001a, 2001b; Lite and Stromberg 2005). Severe droughts and flow modification can reduce growth, decrease reproduction, and increase mortality of mesoriparian and xeroriparian species as well, leading to replacement by small-stature upland plants (Coble and Kolb 2012, 2013; Dewine and Cooper 2007; Stromberg 1993).

Fire Effects

The effects of wildfire on riparian vegetation have received little research attention relative to effects of flood and drought (fig. 4). Fire has long been studied as a method to control the spread of mesquites in rangelands (Blydenstein 1957), but little is known about their response to fire in a riparian setting. Most studies of fire in aridland riparian systems have focused on cottonwoods and saltcedar, largely due to concerns that wildfire will facilitate replacement of the former by the latter (Busch and Smith 1995; Drus 2013; Smith et al. 2009b). Fire effects have been documented infrequently for the other woody taxa (fig. 4). The responses of woody plants to fire in these studies generally include rates of topkill (death of above-ground tissues) and resprouting (production of basal sprouts, epicormic sprouts, and root suckers). Postfire germination has been observed for cottonwoods by Ellis (2001), but direct measurements are not reported in the literature. Boxelder is a widespread and important component of wildlife habitat (Brodhead et al. 2007; Stoleson and Finch 2003), but we did not find reported effects of fire on this species.

Topkill vulnerability varies among taxa, size classes, and fire severity (Bock and Bock 2014; Ellis 2001; Stuever 1997). To our knowledge, all deciduous riparian tree taxa can recover from topkill by producing basal sprouts, epicormic sprouts, or root suckers. The success of vegetative recovery, however, is affected by numerous factors that vary among species and wildfire sites (Ellis 2001; Smith et al. 2009b; Stromberg and Rychener 2010). Examinations of fire that take into account flow modifications, native and nonnative plant responses, and response of animal communities to changes in vegetation are needed. Below we provide an example of this type of study, conducted along the Middle Rio Grande in central New Mexico.

Middle Rio Grande Case Study

The Middle Rio Grande in central New Mexico is anthropogenically modified, but many stretches still support native trees and shrubs, which provide habitat for wildlife

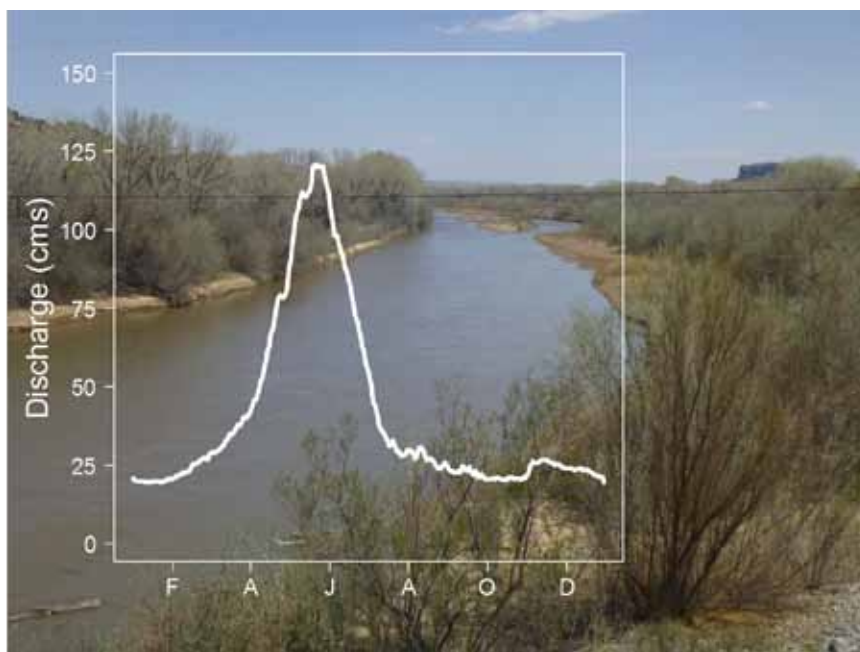


Figure 5—Mean daily discharge hydrograph at the Rio Grande at Otowi, upstream from Cochiti Dam. Line values represent mean daily discharge for each day of the year averaged over the period of 1919 to 2013. Data were obtained from the United State Geological Survey National Water Information System and are available online (<http://waterdata.usgs.gov/nwis>) (photo by Max Smith).

including riparian obligates and threatened and endangered species (Friggins et al. 2013; Smith and Finch 2014). With several decades of research on hydrology, wildfire, plants, and animals, this area is an ideal case study of changing disturbance regimes and their ecological effects.

Natural Hydrological Regime

The Middle Rio Grande is the section of the Rio Grande that flows north to south through central New Mexico. The Rio Grande originates in and receives most of its surface flow from the San Juan Mountains of southwestern Colorado (Phillips et al. 2011). Peak flows, resulting from snowmelt runoff, historically occurred during the late spring or early summer (fig. 5). Floods would cause the channel to migrate throughout the broad alluvial valley, leaving a mosaic of wetlands and multi-aged stands of riparian vegetation (Scurlock 1998). Floods also occurred following heavy thunderstorms during the summer monsoon and other times of the year, but spring snowmelt provided the opportunities for pioneer tree establishment.

Changes to the Regime

Alterations to the Middle Rio Grande have occurred over several centuries, but the stream became profoundly regulated during a period bookended by the formation of the Middle Rio Grande Conservancy District in 1929 and the completion of Cochiti Dam in 1974. To reduce flooding and improve agricultural activity, government agencies constructed a network of diversion dams, levees, irrigation canals, and drains (Phillips et al. 2011; Scurlock 1998). The levees currently prevent the river from meandering across most of the natural floodplain. Within the levees, the stream bank has been stabilized to limit the movement of the active channel. Cochiti Dam, located at the north end of the Middle Rio Grande, has reduced the magnitude of peak flows, but releases from the dam have maintained the seasonal timing of fluctuations (Braun et al. 2015). During years of low runoff, large stretches of the channel become dry as water is diverted for irrigation.

In years with heavy runoff, flood pulses, released from Cochiti Dam, inundate some portions of the area between the levees.

Effects on Riparian Trees

Prior to extensive regulation, riparian forests and herbaceous wetlands were scattered throughout the Middle Rio Grande floodplain in a variety of age classes and seral states (Whitney 1996). Midcentury confinement and channelization of the river led to the establishment of Rio Grande cottonwood bosque that is now sandwiched between the stream channel and the levees. During this time, herbaceous wetlands were lost due to the lowering of water tables and the cessation of channel migration (Crawford et al. 1993). Russian olive, saltcedar, and other nonnative woody species have been in the Middle Rio Grande Basin since the 1930s or earlier and are established throughout the bosque (Scurlock 1998). In terms of stem density, saltcedar is now the numerically dominant woody species in the bosque, followed by cottonwood and Russian olive (figure 3d, Smith and Finch 2014). Cottonwoods and other native trees may die during periods of low precipitation and runoff when depth to groundwater increases (Smith et al. 2009b).

As a result of modification and invasives, composition and arrangement of riparian vegetation are very different from conditions prior to Euro-American settlement. Native and nonnative species now grow in narrow, dense stands that extend from Cochiti Dam to Elephant Butte Reservoir. Without management intervention, flood magnitude is not great enough to scour the forest floor of woody vegetation and deposit sediment for establishment of hydriparian species. In response, cottonwoods and Goodding's willows may be replaced by nonnative trees in the coming decades (Howe and Knopf 1991; Molles et al. 1998).

Historical/Current Wildfire Effects

As the role of flooding has diminished along the Middle Rio Grande, wildfire has grown from a minor component of the disturbance regime to an increasingly important influence on plants and animals (Crawford et al. 1993; Finch et al. 2006; Stuever et al. 1995; Williams et al. 2007; Bess et al. 2002). Most fires that enter the bosque are accidentally ignited and burn with mixed intensity until they are contained by firefighting crews. The number of ignitions increases with proximity to larger towns and cities, but the size of fires increases with distance from these areas (Williams et al. 2007). Most fires occur in the dry spring and early summer period and the number of fires tends to be greater during years with low precipitation (Stuever et al. 1995). Since the beginning of a long-term drought in 2000, at least 40 percent of a 732-ha study area has burned and some portions have burned multiple times (Smith and Finch 2017). With the lack of high-magnitude flooding, the bosque has accumulated large quantities of litter and woody debris. Nonnative plant species, especially Russian olive and saltcedar, have spread as soil moisture declined, increasing the density of woody plants in the understory (Bateman et al. 2008). These fuels, combined with the spatial arrangement of the forest, have contributed to increasing fire sizes and intensities that are likely outside the natural range of variability in the Middle Rio Grande (Bateman et al. 2008; Ellis 2001; Johnson and Merritt 2009).

Response of Woody Plants to Wildfire

Several studies have examined responses of native and nonnative woody vegetation to wildfire in the Middle Rio Grande. Results are varied, indicating that spatial and temporal factors interact with fire in shaping riparian forest composition. Several patterns, however, have emerged with the response of cottonwood and other woody plants.

Cottonwoods are extremely vulnerable to topkill from fires that enter the bosque (table 1). Most, if not all, above-ground mortality occurs immediately after fire. In areas where fire severity is high (all organic matter is consumed on the forest floor), all cottonwoods and other woody species are top-killed. Topkill rates are lower for trees in areas burned with moderate severity (78 to 100 percent of trees killed) and light severity (52 to 70 percent of trees killed) (Ellis 2001; Stuever 1997). Managed flooding and mechanical fuel reduction can increase resistance to topkill of cottonwood, but only to a limited extent given their high vulnerability to fire and the difficulty of removing all sources of fuel from the understory (Ellis 2001; Johnson and Merritt 2009). Woody riparian plants recover vegetatively from wildfire through production of basal sprouts, root suckers, and (in the case of cottonwoods) epicormic sprouts. Their production and survival, however, vary among species and study sites (Ellis 2001; Smith et al. 2009b). We observed epicormic sprouting of cottonwoods only at one site that burned with light to moderate severity.

We observed postfire germination of cottonwoods at a site burned in March of 2008 and partially flooded in June of that year. Ellis (2001) also observed saplings in postwildfire sites along the Middle Rio Grande that were flooded within 2 years of being burned. A combination of fire and low-magnitude flooding can therefore act as a replacement for high-magnitude flooding along this heavily regulated stream.

Ecosystem Implications of the Current Disturbance Regime

Despite its highly regulated state, the Middle Rio Grande supports a unique assemblage of wildlife species. In unburned portions of the bosque, large cottonwoods provide nest sites, shelter, and food for reptiles, birds, and mammals (Finch et al. 2006; Smith and Finch 2014; Smith et al. 2006). Cavities in cottonwood snags and broken branches of live cottonwoods are used for nesting and roosting sites. Smaller woody plants, including Russian olive and saltcedar, provide resources such as nest sites for birds in the shrub and subcanopy nesting guilds (Finch et al. 2006; Smith and Finch 2014; Smith

Table 1—Estimates of top-kill and basal sprouting rates at four sites along the Middle Rio Grande. The San Pedro burn sites were measured by Ellis (2001) in 1996. We measured the 3-4-6 and Sevilleta burn sites in 2013.

	Topkill				Basal sprouting			
	San Pedro Burn 1 (1996)	San Pedro Burn 2 (1996)	3-4-6 Burn (2011)	Sevilleta Burn (2011)	San Pedro Burn 1 (1996)	San Pedro Burn 2 (1996)	3-4-6 Burn (2011)	Sevilleta Burn (2011)
.....Percent.....								
Cottonwood	100	97.7	100	95	77	81	21.2	56.8
Saltcedar	100	100	95	NA	53	55	84.9	NA
Russian olive	NA	NA	97	100	NA	NA	85.7	75.7

et al. 2009a). Wildfire removes cottonwood canopy, creates snags and fallen debris, and induces resprouting of woody plants, especially saltcedar. These changes to forest structure and composition create habitat features used by many animal species, but make the bosque unsuitable for others (Smith et al. 2007, 2012). As postfire succession occurs, density of canopy-dependent species will decline if cottonwoods do not recover. In addition, cavity-associated species will lose nest and roosting sites if fallen snags are not replaced by mature trees.

Under the current disturbance regime, mortality of large riparian trees will continue to increase due to wildfire, drought, and senescence (Smith and Finch 2015). Vegetative and sexual reproduction of cottonwood and other native trees may occur under certain circumstances, such as fire and flood events and management intervention that are limited in spatial scale (Howe and Knopf 1991). Nonnative woody species, such as Russian olive and saltcedar, are present throughout the Middle Rio Grande and will likely increase in abundance as cottonwood declines. With high densities of mesoriparian and xeroriparian growth, postwildfire sites are vulnerable to additional high-severity fires and may enter a positive feedback loop, to the detriment of native hydriparian species (Drus 2013). Postwildfire replacement of cottonwood by Russian olive and saltcedar will change the structure of the Middle Rio Grande riparian forest by increasing the density of low-stature vegetation and decreasing canopy height, in turn affecting habitat quality for wildlife, including riparian-nesting birds.

Implications of Climate Change

Projected effects of climate change are particularly severe in the Southwest (Gutzler and Robbins 2011; Seager et al. 2007). Increasing temperatures and changes in precipitation will affect characteristics of streams, which in turn shape aridland riparian ecosystems (Seager et al. 2013) and their capacity to support wildlife (Friggens and Finch 2015). For example, global climate models predict that, in the Rio Grande Basin, increasing temperatures will result in decreased snowpack, decreased runoff, and earlier peak discharge (fig. 6). Such changes could further limit reproduction of cottonwoods and willows, increase drought mortality, and decrease their ability to recovery from wildfires relative to Russian olive and saltcedar (Smith et al. 2009b). In addition, storms such as those during monsoons may gain strength in response to warming. Resulting floods could induce late summer germination of mesoriparian and xeroriparian species, to the exclusion of species with narrower windows of seed viability (Dewine and Cooper 2007; Fenner et al. 1985; Katz and Shafroth 2003). Replacement of hydriparian species by mesoriparian and xeroriparian species would have cascading effects on the riparian forest community.

Conclusions: Disturbance Change and the Future of Aridland Riparian Forests

Studies of woody riparian plants show that effects of disturbances on survival and reproduction vary among species. As our Middle Rio Grande study shows, native hydriparian pioneer species are vulnerable to changes in streamflow, which, coupled with wildfire effects, could open doors to invasion by xeroriparian and upland species. As with other aridland rivers, the Middle Rio Grande has created an extensive riparian

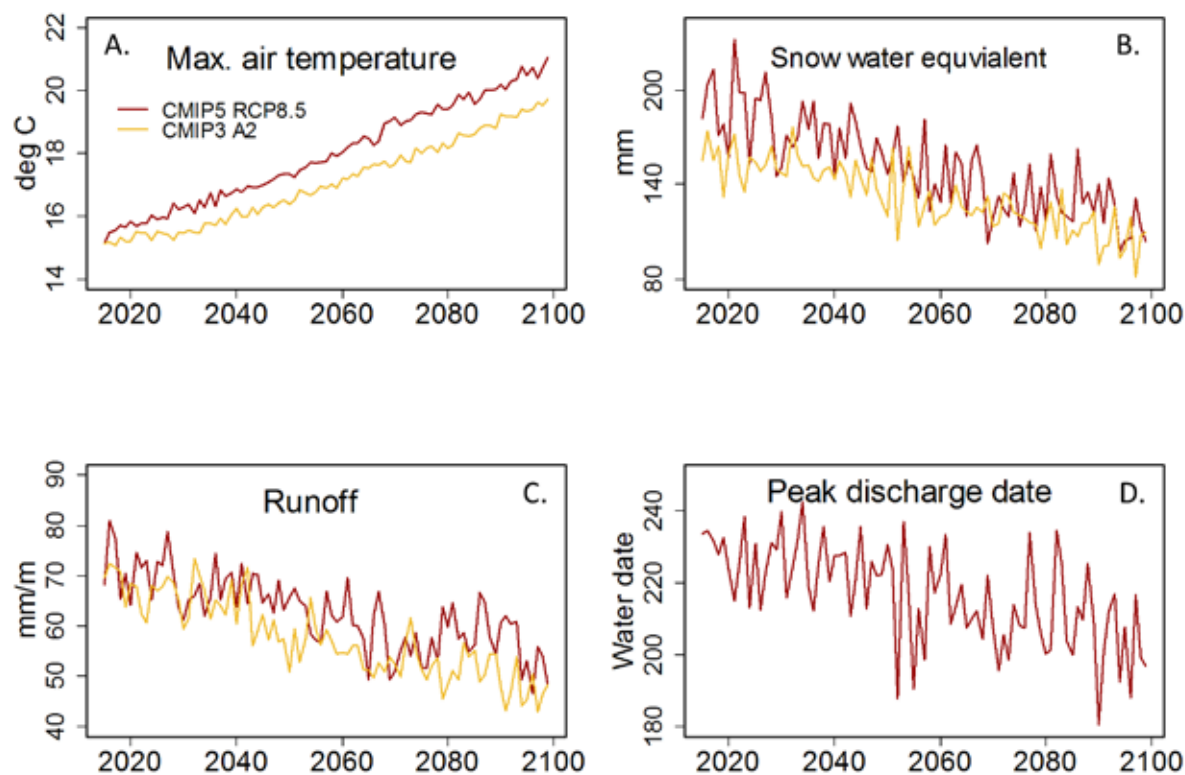


Figure 6—Temperature and hydrological projections for the Rio Grande Basin. Boxes A–C contain projections by 29 models run under the CMIP5 RCP8.5 scenario and 16 models run under the CMIP3 A2 scenario. Box D contains projections of peak discharge date for the Rio Grande at Otowi from 15 models run under the CMIP3 A2 scenario. Projections were made by the U.S. Bureau of Reclamation and are available online (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html).

corridor critical to the successful migration, reproduction, and overwintering of myriad wildlife species (Carothers et al. 1974; Knopf and Sampson 1994; Bateman et al. 2008). Maintaining the composition of these corridors is necessary to preserve both regional and continental biodiversity.

During the previous decades of riparian research, ecologists have highlighted the importance of woody riparian vegetation to wildlife and have described the response to changes in hydrology. For most riparian taxa, however, response to wildfire, especially in combination with drought, is poorly known or has been examined in only a few locations. As climate changes and wildfire becomes more frequent than flooding, information on how fire, drought, and climate change affect riparian vegetation will be critical for managers in maintaining ecosystem structure and stability, wildlife habitat, and the associated animal populations and communities. Because riparian dynamics, including recovery from wildfire, are coupled with hydrology of regulated streams, we need hydrological projections that incorporate future water use and climate change scenarios. With this information, we can determine which species of plants will naturally sustain themselves and which will require adaptive management in an increasingly arid Southwest.

Acknowledgments

We appreciate input from Megan Friggins and comments from multiple reviewers. Funding for this work was provided by the Desert and Southern Rockies Landscape Conservation Cooperatives and the USDA Forest Service Rocky Mountain Research Station.

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