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Riparian Forests

Assessing South Platte River Phreatophytes following the Flood of 2013

Colorado State University

Special Issue— South Platte Phreatophytes

In Every Issue

On the cover

An aerial view of Sterling Irrigation Company Ditch #1 and Springdale Ditch on the South Platte River, Sterling, Colorado, Photo by William A. Cotton/CSU Photography

At right: The South Platte Ditch on the South Platte River pictured near Merino, Colorado

William A. Cotton/CSU Photography

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Riparian Forests

Assessing South Platte River Phreatophytes following the Flood of 2013

Reagan Waskom

Phreatophytes, those deep-rooted water loving trees such as cottonwoods or willows, are seen by some as water thieves, by others as critical components of healthy riparian ecosystems. Long a subject of contention, we know from historical records and current encroachment of invasive species, how the riparian forest has been in a state of flux since European settlers began altering the river systems in the 1800's, first through trapping, then logging, mining, human settlement and flow diversion for agriculture and industry. There is evidence that Native American settlements also impacted the riparian forests, as did grazing by buffalo and later, domesticated livestock. Riparian forest composition and extent in Colorado have likely been under significant and continuous change since water development began in the mid-19th Century. We now know that this process is largely driven by both short- and long-term patterns of river discharge within the system.

Phreatophytes are associated with all riparian corridors to various degrees, but non-native and invasive phreatophytes are a source of particular concern for both water users and environmental interests. Water users have long known that phreatophytes were capturing and transpiring water that was part of the stream system. The issue of whether removing phreatophytes increases water supply has been studied for many years, and little empirical evidence exists that tree removal will sustainably increase water supply, as other plants will quickly recolonize these areas unless strict control is maintained.

In 2014, the Colorado legislature passed SB14-195, directing the Colorado Water Conservation Board to study the effects of the September 2013 South Platte flood on phreatophyte spread and the feasibility of removing non-native phreatophytes from the South Platte River corridor.

U.S. Army photo by Staff Sgt. Wallace Bonner

An aerial view of floodwaters in Colorado in September 2013.

In 1975, the Colorado Supreme Court ruled in the Shelton Farms case that water salvaged from the removal of phreatophytes belongs to the watershed, not the individual who reduces evapotranspiration by removing these thirsty plants. Nonetheless, the State and the Basin Roundtables understand the need to manage the riparian forests to maintain the integrity of our river systems, particularly in the face of invasive non-natives such as tamarisk.

The September 2013 flood on the Colorado Front Range occurred due to an unusually heavy and prolonged rainfall event over a large area of the foothills, resulting in an exceptional flood event on the South Platte River. Record rainfall amounts were measured in several areas with the previous one-day state record of 11.08 inches of precipitation exceeded at Fort Carson, where 11.85 inches fell on September 12, 2013. The flood inundated large stretches of the floodplain from communities along the Front Range all the way to Nebraska, causing heavy damage, exceeding an estimated $2 billion in property loss, plus 10 fatalities. As the floodwaters reached the eastern plains along the river, widespread local flooding occurred as massive amounts of water moved through the system. Reconstructed estimated peak flood flows at Kersey in September 2013 were on the order of 55,000 cubic feet per second (cfs), while typical September flows at the Kersey gauge are in the neighborhood of 500 cfs. As a result, significant quantities of sediment, plants and debris were scoured and redistributed in the floodplain.

Estimated total costs for removing 20% of phreatophytes from reaches along the South Platte below Denver range from $870,700 for one-time removal only, to $45,524,846 for removal plus weed control, seeding, and shrub planting.

Following the September 2013 flood, there was concern that new sediment deposits, elevated groundwater levels, and altered stream banks would result in an increase the abundance of invasive non-native species, including woody phreatophytes and State of Colorado-listed noxious weeds. In 2014, the Colorado legislature passed SB14-195, directing the Colorado Water Conservation Board to study the effects of the September 2013 South Platte flood on phreatophyte spread and the feasibility of removing non-native phreatophytes from the South Platte River corridor. SB 14-195 directed the Colorado Water Conservation Board to: "*conduct at least the preliminary stages of a comprehensive study to evaluate the growth and identification of phreatophytes along the South Platte River in the aftermath of the September 2013 flood*". The CWCB subsequently contracted with Colorado State University and the Tamarisk Coalition to conduct the required studies. Interestingly, both 2014 and 2015 were also high water years with some flooding on the South Platte, no doubt further impacting the trajectory of channel morphology, phreatophyte recruitment and survival. Research has shown that maintenance of cottonwood and willow forests depends upon periodic flooding and disturbance patterns that allow for both seedling establishment and long-term survival. In the absence of appropriate levels of disturbance, vegetation dynamics will likely follow one of two possible trajectories: forest succession could shift in composition from cottonwood-willow to non-pioneer species such as green ash, Siberian elm and Russian olive, or mortality of cottonwoods could result in a shift to grassland conditions.

The study, led by CSU Professor Andrew Norton, documented that the riparian forest along the South Platte River is dominated by Plains cottonwood, while the second most common mature tree species is the Peachleaf willow. Currently, the most common non-native phreatophytes in the study area are Russian olive and Siberian elm. They estimated that non-native phreatophytes make up between 4 and 10% of the riparian forest on a per-area basis. It was also estimated the 2013 flood and subsequent high water years in 2014 and 2015 caused the mortality of 8.5% of the forest, on an area basis. The flood opened up new areas for cottonwood seedling germination and establishment that occurred during 2014 and 2015 but it is not yet known whether these seedlings will survive to become saplings or mature trees. Estimated total costs for removing 20% of phreatophytes from reaches along the South Platte below Denver range from $870,700 for one-time removal only, to $45,524,846 for removal plus weed control, seeding, and shrub planting. Continued monitoring will be needed to assess long-term trends in riparian forest spatial extent, dynamics of cottonwood regeneration, and successional trajectories for species composition within aging forest stands. A key question that remains from the work is how frequently cottonwood seedlings successfully recruit to the sapling stage within this system.

This edition of *Colorado Water* newsletter provides an overview of findings and recommendations related to effects of the 2013 flood on the riparian forest of the South Platte River in northeast Colorado. For supporting documentation and a more detailed summation, please see the full report found online at http://cwi.colostate.edu/publications/SR/30.pdf.

Reagan Waskom
Director, Colorado Water Institute

Rich Keen/DPRA, Inset: iStock.com

How River Hydrology Affects Riparian Trees on Rivers of the Great Plains[1]

Gabrielle Katz, Assistant Professor, Department of Earth and Atmospheric Sciences, Metropolitan State University of Denver

Introduction

Floodplain ecosystems are among the most dynamic on earth, experiencing the ecological disturbances typical of uplands as well as those unique to the river system itself (e.g., flooding, erosion, sedimentation; Rood et al. 2007). On most rivers, the *river flow regime*, the pattern of discharge variability through time, is the key driver shaping riparian ecosystems (Poff et al. 1997). Thus, riparian vegetation patterns result from the interaction of plant adaptations with river hydrology and geomorphic processes, including current hydrologic conditions as well as past streamflows. The purpose of this article is to describe how river hydrology influences the reproduction and survival of the dominant riparian tree species and the role of river dynamics in shaping riparian forest patterns in space and time.

Hydrology and Tree Recruitment

Cottonwoods, willows, and tamarisk are all *pioneer species* whose reproduction depends on river-related disturbance to create sites for seedling establishment. In contrast, the reproductive ecology of later successional species (e.g., Russian olive, Siberian elm, boxelder and green ash) is less linked to river processes, and recruitment can occur in the absence of flooding or physical disturbance. In this context, *establishment* refers to the process of plant establishment in a new location, usually by seed but sometimes vegetatively. *Survival* refers to the persistence of the seedling through subsequent growing seasons, typically at least three years. *Recruitment*, membership in the future adult population, results from both establishment and survival (Rood et al. 2007). Thus, recruitment of riparian tree species is impacted by river dynamics and hydrologic conditions that affect both initial seedling establishment and longer term tree survival.

Native Cottonwoods and Willows

Seeding establishment of cottonwoods and willows tends to occur on bare, moist sediments deposited or exhumed by dynamic river processes. This article focuses on sexual reproduction by seed and its links to hydrology. However, for many riparian species (e.g., willows, native balsam poplars, and the non-native crack willow) asexual vegetative reproduction also can be an important mode of regeneration linked to river hydrology (Karrenberg et al. 2002, Rood et al. 2007).

Seed dispersal of cottonwoods and some willows coincides with, or immediately follows, natural stream peak flows. Cottonwoods produce seeds during a short time period (< 2 months) in spring or early summer, when snowmelt produces high flows in many western rivers. Seeds remain viable for only a few weeks, and germinate rapidly. In the eastern plains of Colorado, cottonwood peak seed release tends to occur in June, though this varies depending on individual tree characteristics, local conditions, and yearly weather.

Initial seedling establishment of cottonwoods and willows typically occurs on areas of moist sediment that are free of competing vegetation and plant litter (Auble and Scott 1998). Cottonwood seedlings are intolerant of shade, and rarely establish within intact herbaceous vegetation, or beneath forest canopies. Cottonwood and willow seedlings are also intolerant of desiccation, relying on constantly available moisture for survival. Because of these constraints, in any given year cottonwood and willow seedlings usually become established adjacent to, or within, the active channel zone where bare moist substrate is available

[1] This article is based on the literature review River Hydrology and Riparian Trees, which was submitted to the Colorado Water Conservation Board as part of the South Platte Phreatophyte Survey final report

William A. Cotton/CSU Photography

The South Platte River pictured near Atwood, Colorado. Seeding establishment of cottonwoods and willows tends to occur on bare, moist sediments deposited or exhumed by dynamic river processes.

for colonization (Friedman et al., 1997, Stromberg 1997).

Mortality rates of close to 100% are commonly observed for first-year cottonwood and willow seedlings. Seedlings established within the active channel zone are extremely vulnerable to removal by subsequent stream flows (Stromberg 1997, Auble and Scott 1998, Rood et al. 1998). On the other hand, seedlings established at more elevated positions are vulnerable to lethal summer drought stress. In a pattern likely typical of seedling dynamics in most years, Sedgwick and Knopf (1989) found high mortality of first-year plains cottonwood seedlings on the South Platte River in 1984, a summer with average precipitation and discharge patterns; of 100 micro-plots containing seedlings in late June, 3 contained live seedlings by mid-September, representing a 97% decrease in seedling frequency and a 99% decrease in seedling density.

In order for seedling establishment to lead to recruitment into older age classes, cottonwood and willow seedlings must be protected from perpetual inundation, complete burial by sediment, scouring by water and ice, and drought stress. Thus, long-term seedling survival occurs on bare patches characterized by both adequate moisture and protection from lethal levels of physical disturbance (Auble and Scott 1998, Mahoney and Rood 1998, Rood et al. 1998). Such protected sites may occur in localized geomorphic situations such as the downstream ends of islands, but are more commonly found outside of the active channel area. Regardless of establishment location, successful recruitment of cottonwood seedlings depends on their ability to access groundwater. As riparian water tables recede following normal spring flooding, root growth must keep pace or the seedlings will desiccate and die. Successful recruitment of cottonwood seedlings generally occurs ~60-150 cm above river base flow elevation (Mahoney and Rood 1998). Presumably, the lower elevation limit is determined by erosional processes, while the upper limit results from the combination of seedling root elongation potential and the depth of the riparian water table.

Tamarisk

Similar to native cottonwoods and willows, the non-native tamarisk is a riparian pioneer species whose reproduction is linked to river-related physical disturbance. Tamarisk produces large numbers of very small wind and water dispersed seeds (Brock 1994). The seeds are short lived, and lose germinability after a few weeks. Optimal germination sites for tamarisk are moist, fine silt deposits (Brock 1994). Seedling establishment typically occurs on bare moist surfaces, such as along the high water line following flood events (Glenn and Nagler 2005).

However, there are several aspects of tamarisk reproductive ecology that differ importantly from that of native cottonwoods and willows. In contrast to the limited seed dispersal periods of native cottonwood and willow species, tamarisk seeds are dispersed throughout the spring and summer (Brock 1994). Thus, tamarisk can establish on fluvial disturbance patches created later in the summer, allowing it to flourish on rivers with altered flow regimes (Glenn and Nagler 2005). In addition, tamarisk seedlings have faster root elongation rates and greater rooting depths than native cottonwoods and willows, enabling them to survive better where water conditions are less favorable (Hultine and Bush 2011). Although its reproduction is tied to river-related disturbance, tamarisk establishment occurs in a broader range of micro-environments than cottonwoods and willows, e.g., on higher terrace surfaces.

Russian olive

The reproductive ecology of Russian olive is not strongly tied to river hydrology, allowing recruitment to occur under a broad range of conditions. In contrast to riparian pioneer species, Russian olive produces large fruits that ripen in late summer or fall. Fruits are dispersed by birds and mammals, as well as by gravity and water. After dispersal, Russian olive seeds can survive in the soil, forming a soil seed bank (Brock 2003). Seeds are dormant when they are dispersed, requiring a period of over-winter cold stratification for germination to occur (Guilbault et al. 2012). Russian olive seedling establishment occurs under a variety of environmental conditions, including a range of moisture conditions and shade levels (Katz and Shafroth 2003, Reynolds & Cooper, 2010). Therefore, Russian olive seedlings and adults grow in the understories of riparian gallery forests, as well as in open meadow habitats (Katz et al. 2005, Reynolds and Cooper 2010).

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Russian olive (elaeagnus angustifolia)

Impacts of Hydrology on Mature Riparian Forests

The survival and performance of adult riparian trees depends on the balance between flooding and drought. This section describes how hydrology affects long-term survival of established riparian trees, including cottonwood, willow, tamarisk, and Russian olive.

Flooding

In the short term (i.e., days to years), flooding can result in substantial mortality to riparian trees. However, in the long term (i.e., decades) flooding generally promotes rejuvenation and renewal of floodplain forest ecosystems, via its effects on recruitment of native cottonwoods and willows (see above). The short-term deleterious effects of flooding on riparian trees will depend on the magnitude and duration of the flood event, the spatial pattern of forest exposure to flood impacts, as well as the flood/inundation tolerance adaptations of each species. For example, a large flood on the Missouri River in 2011 resulted in higher mortality rates in young forest patches compared to older patches, and preferential mortality of non-pioneer species (i.e., Russian olive and redcedar; Dixon et al. 2015).

Direct physical damage by moving flood waters can kill adult riparian trees of all species. Moving flood waters may carry debris and ice which can severely damage trees, and in the extreme, the hydraulic force of flood waters can completely remove established trees. For example, a large flood on Plum Creek, Colorado in 1965 sheared off or uprooted half of the adult bottomland cottonwood and willow trees (Friedman et al. 1996). In northern latitudes the breakup of winter river ice, followed by its transport downstream and subsequent local jamming, damming, breakage and surge, can be the most extreme physical disturbance in riparian ecosystems (Rood et al. 2007).

Prolonged inundation can also damage or kill adult riparian trees. The primary effect of inundation is usually an immediate reduction in soil aeration. Additional effects include changes in microbial communities and processes, changes in soil redox potential and pH, and presence of phytotoxic compounds in waterlogged soils (Kozlowski et al. 1991). Cottonwood and willow adults are fairly well adapted to flooding, possessing a variety of physiological adaptations to cope with inundation (Kozlowski et al. 1991, Amlin and Rood 2001). Despite these adaptations, adult cottonwoods cannot survive permanent inundation, and are commonly killed by flooding associated with reservoirs or beaver dams. Similar to native cottonwoods and willows, tamarisk is fairly tolerant of prolonged, but not permanent, inundation. Russian olive appears to be less tolerant of inundation than native cottonwoods and willows.

Drought

Native cottonwoods and willows are not drought tolerant, and require access to riparian groundwater for long-term survival. This reliance on alluvial groundwater generally limits the occurrence of adult trees to streamside banks or floodplain elevations up to 3-4 m above the base stage of the river in late summer (Stromberg et al. 1996). Alluvial groundwater declines can cause drought stress and/or mortality of adult cottonwood trees, if roots cannot maintain contact with deepening groundwater sources. Physiological responses to drought in riparian cottonwoods include reduced photosynthesis, reduced growth, early leaf senescence, branch sacrifice, crown die-back, and mortality (reviewed in Rood et al. 2003). Many studies have documented loss (mortality) of adult cottonwoods and willows during climatic drought or in response to anthropogenic stream dewatering on rivers in western North America, e.g., Virgin River, Utah; Big Lost River, Montana; Saint Mary River, Alberta, Canada (Rood et al. 2003, Glenn and Nagler 2005).

Tamarisk is more drought tolerant than native cottonwoods and willows. Indeed, drought tolerance is a key factor enabling tamarisk to become a dominant riparian species in the southwestern U.S., allowing it to establish and persist in habitats that are not suitable for most other riparian species (Hultine and Bush 2011), and where periodic natural drought and/or anthropogenic groundwater decline result in mortality of native riparian tree species (Glenn and Nagler 2005).

Russian olive is also more drought tolerant than native cottonwood and willow species, and appears to be at least as drought tolerant as the non-native tamarisk (Katz & Shafroth 2003). Russian olive can establish on higher and drier geomorphic surfaces compared to cottonwood in the Great Plains (Katz, et al. 2005), and compared to both cottonwood and tamarisk in the Colorado Plateau (Reynolds and Cooper 2010). Although Russian olive

Zach Mahone

Contractor Stan Young performs mechanical control of Tamarisk and Russian olive trees near Grand Junction, Colorado.

is not a truly xeric species, it can establish and survive for long periods utilizing only soil water, not groundwater (Reynolds and Cooper 2010).

River Processes and Forest Patterns

The plant adaptations described above combine with river hydrology and geomorphic processes to create distinct riparian forest patterns on different kinds of rivers (Scott et al. 1996, Scott et al. 1997). On meandering rivers with fine sediment, moderate flows cause the migration of river bends -- progressively eroding banks on the outsides of bends, and progressively depositing sediment (point bars) on the insides of bends. Point bars provide seedling establishment sites that become increasingly protected from flooding as the river migrates farther away and as sediment deposition builds up the bar. Thus, on meandering rivers, natural flow variability results in cottonwood establishment at relatively frequent intervals, corresponding to discharges typical of the 1-in-3 or 1-in-5 year floods (Rood et al. 2007). This process yields a riparian forest comprised of narrow, arc-shaped bands of even-aged trees. In contrast, on bedrock streams where rivers are constrained in narrow valleys, sediment deposition and scouring by infrequent large floods are the most important processes creating recruitment sites for pioneer species. This process produces narrow linear bands of even-aged trees (Scott et al. 1997).

On braided rivers, the primary mode of riparian forest establishment is channel narrowing. Braided rivers are naturally wide and shallow, with a coarse sediment load; stream flow is distributed among multiple, shifting channels separated by transient sand or cobble bars within the active channel zone. Narrowing of a braided channel can occur when there are ≥1 years of stream flows lower than that required to re-work the channel bed sediments. This allows vegetation to establish on the formerly wide channel bed. Thus, on braided rivers, cottonwood establishment tends to be associated with periods of low flow (Friedman et al. 1996). The newly established vegetation in turn promotes sediment deposition and resists erosion, stabilizing a narrower channel configuration. In the Great Plains physiographic region in Colorado, riparian forest establishment associated with channel narrowing has been documented after flood-induced channel widening (e.g., on Plum Creek, Friedman et al. 1996; on the Arikaree and South Fork Republican Rivers, Katz et al. 2005; and on Bijou and Kiowa Creeks, tributaries of the South Platte River, Friedman and Lee 2002), downstream of dams (e.g., on the Arkansas River, Friedman et al. 1998), and in response to land use and water management changes (e.g., the South Platte River, Nadler and Schumm 1981). Forest establishment by this process can occur over several decades, producing uneven-aged tree stands with variable spatial patterns. This mode of forest regeneration is highly episodic and infrequent on unregulated rivers of the western Great Plains, with the recurrence of flood induced channel widening (the precursor to narrowing) possibly exceeding the lifespan of the cottonwoods and willows that comprise the riparian forest (Friedman et al. 1996, Friedman and Lee 2002).

Conclusion

Riparian ecosystems are dynamic, shaped by flooding and river channel movement over time. Riparian forest patterns result from the combination of plant adaptations and the physical processes operating on specific rivers. Understanding these processes is critical to effective management of riparian forests.

William A. Cotton/CSU Photography

The South Platte River pictured at Highway 6 near Merino, Colorado.

History and Future of the South Platte River Riparian Forest[1]

Gabrielle Katz, Assistant Professor, Department of Earth and Atmospheric Sciences, Metropolitan State University of Denver

Introduction

East of the foothills in Colorado, the South Platte River currently supports a broad riparian forest dominated by plains cottonwood (*Populus deltoides*), with peachleaf willow (*Salix amygdaloides*) also abundant at some sites (Sedgwick and Knopf 1989, Johnson 1994). These cottonwood and willow species are native, riparian pioneer species whose ecology is strongly linked to river-related disturbance processes and hydrology. The non-native tamarisk (*Tamarix* spp.) is another riparian pioneer species, infrequently present at low abundance in the South Platte River system. Additional tree species present at low abundances are green ash (*Fraxinus pennsylvanica*), boxelder (*Acer negundo*), Siberian elm (*Ulmus pumila*), and Russian olive (*Elaeagnus angustifolia*). These species are later successional species, whose reproduction is not strongly tied to physical disturbance. Of these non-pioneer species, Russian olive and Siberian elm are non-native in North America; green ash is native in eastern North America; and boxelder is native in the South Platte River system. There likely would be more Russian olive and tamarisk in the South Platte system in Colorado, except that both species have been the subjects of control measures. Tamarisk, in particular, has been aggressively controlled on Colorado State Wildlife Areas in eastern Colorado. Russian olive and tamarisk were removed from most properties in Weld County on the Cache la Poudre River in 2010, Saint Vrain Creek in 2014, and the Big Thompson River and South Platte River mainstem in 2016. The South Platte River riparian forest is a valued natural resource, providing important wildlife habitat, water quality enhancement, and recreation opportunities (Strange et al. 1999).

History of the South Platte River

The hydrology of the South Platte River today differs significantly from historic conditions (Nadler and Schumm 1981, Johnson 1994, Strange et al. 1999, Waskom 2013). Prior to water development, the South Platte River experienced an annual hydrograph

[1] This article is based on the literature review *River hydrology and riparian trees: Literature review* submitted to the Colorado Water Conservation Board as part of the South Platte Phreatophyte Survey Final Report.

Riparian Vegetation Dynamics

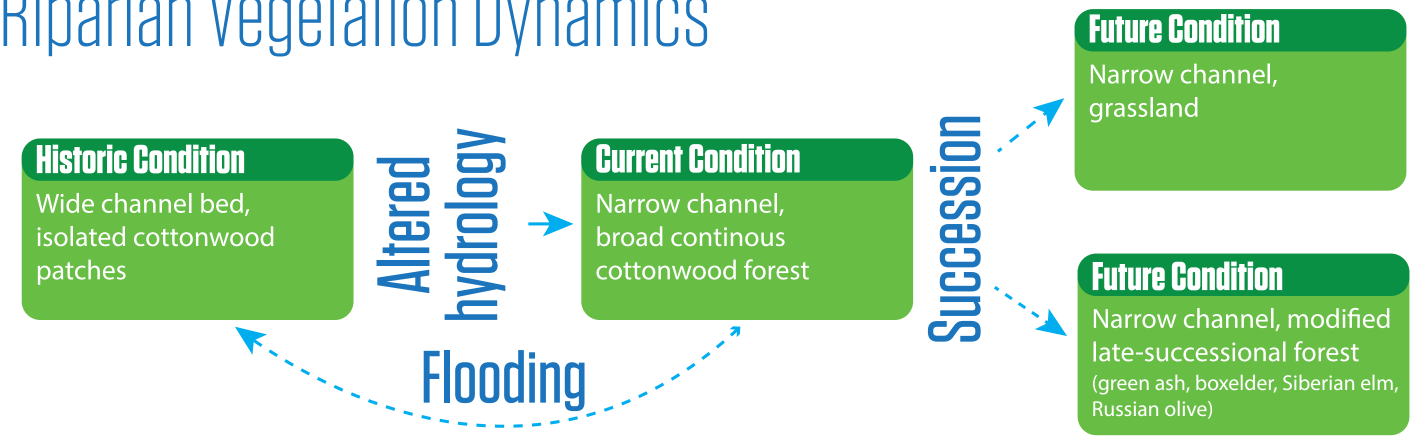

Figure 1. Conceptual model of historic vegetation dynamics (solid arrow), and possible future conditions (dashed arrows), of the South Platte River riparian forest in eastern Colorado (modified from Friedman et al. 1997, Strange et al. 1999). Ecological succession could lead to grassland or a modified late-successional forest dominated by non-native species. Alternatively, flooding could widen the channel and lead to renewed cottonwood forest establishment (i.e., channel narrowing).

dominated by mountain snowmelt, with high flows typically occurring in May and June, and low flows occurring in late summer. There was substantial inter-annual variability in flow, resulting from climate fluctuations. In addition, late summer thunderstorms occasionally produced large floods in tributaries that affected flow in the mainstem (e.g., West Bijou and Kiowa Creeks, Friedman and Lee 2002). Water development in the South Platte Basin began in the 1840's, and the system now includes >18,500 diversion points, as well as considerable water inputs from trans-basin diversions and return flows from irrigation groundwater (Strange et al. 1999, Waskom 2013). One key effect of water management has been the stabilization of South Platte River streamflow (i.e., reduced seasonal flow variation) and augmentation of the alluvial aquifer by seepage from the vast network of irrigation ditches, canals and reservoirs (Waskom 2013). However, there is still substantial inter-annual variation in streamflow; for example, annual flow at Julesburg, Colorado ranged from 30,355 acre feet to 2,130,245 acre feet between 1925 and 2012 (Waskom 2013). Large floods still occasionally occur in the river, such as occurred in September, 2013. Thus, the South Platte River is a highly modified system that nonetheless experiences substantial hydrologic variability relevant to the structure and functioning of riparian ecosystems.

Prior to the era of water development in the basin (circa 1880), the South Platte River east of the foothills had a wide, braided form, with multiple, shifting channels and many sand bars and islands. The historic annual flow regime of the South Platte River was dominated by spring snowmelt from the Rocky Mountains, with low flows occurring in late summer. The combination of high spring flows that reworked channel bed sediments and eroded seedlings, and low late summer flows that created drought conditions, limited the extent of forest vegetation in the riparian zone. Thus, pre-development riparian vegetation was characterized by a mosaic of grasslands, marshes, and isolated woodland patches (Johnson 1994).

The present-day broad, spatially continuous cottonwood forest on the South Platte River in eastern Colorado became established between 1900 and ~1930, as the wide river channel became narrower in response to anthropogenic hydrologic alterations (Nadler and Schumm 1981, Johnson 1994). Beginning in the 1880's the flow of the South Platte River was progressively stabilized and augmented by dams, sub-surface irrigation return flows and trans-basin diversions, raising riparian water tables in some areas (Nadler and Schumm 1981). These hydrologic changes, coupled with occasional droughts, allowed cottonwood and willow to establish on the former channel bed. By 1937, ~90% of the formerly active channel area on the South Platte River in eastern Colorado was vegetated (Johnson 1994). This vegetation, in turn, stabilized channel morphology and further promoted the narrowing of the river to its present day single thread, more sinuous form. Today, the main pulse of forest expansion appears to have stopped as the area available for colonization has been reduced and a new equilibrium channel width has been attained.

Possible futures for the South Platte River riparian forest

The long term persistence of a riparian cottonwood forest on the South Platte River in eastern Colorado depends upon river-related geomorphic processes (i.e., sediment erosion and deposition) and hydrologic conditions (i.e., flow dynamism and groundwater levels). Because cottonwoods and willows are *pioneer species*, a steady state forest over the long term requires dynamic processes of flooding, erosion and sediment deposition to create suitable seedling establishment sites. These processes can be episodic, but must occur frequently enough to rejuvenate the forest as mature cottonwoods senesce and die. Alternatively, in the absence of appropriate levels of fluvial disturbance, vegetation dynamics might follow two possible trajectories—(1) forest succession could result in a shift in forest composition to non-pioneer species such as green ash, boxelder, Siberian elm, Russian olive and eastern juniper

The Prewitt Inlet Canal and Tetsel Ditch is located near Hillrose, Colorado. Evapotranspiration from the riparian forest has been mentioned as a concern in the context of water resources management.

(Sedgwick and Knopf 1989, Johnson 1994), or (2) mortality of cottonwoods could result in a shift to grassland conditions (Figure 1, Friedman et al. 1997).

> Both Sedgwick and Knopf (1989) and Johnson (1994) cautioned that the cottonwood forest on the South Platte River was likely undergoing succession to less ecologically valuable species, and that the future riparian forest would be dominated by non-pioneer species.

Recent research on the South Platte River has yielded contrasting assessments of the status of the riparian forest. According to one view, the present-day riparian forest represents a discrete episode of channel narrowing that is now over. Johnson (1994) concluded that the forest extent on the South Platte River system overall was in a dynamic steady state, focusing mostly on sites in Nebraska that showed stabilized proportions of active channel vs. vegetated floodplain area since the 1960's. Both Sedgwick and Knopf (1989) and Johnson (1994) cautioned that the cottonwood forest on the South Platte River was likely undergoing succession to less ecologically valuable species, and that the future riparian forest would be dominated by non-pioneer species. Thus, these authors interpreted the twentieth century channel narrowing/cottonwood establishment event on the South Platte River as a historic occurrence that is not ongoing. That is, a new equilibrium channel width has been attained (Friedman et al. 1997), and ecological succession is now the dominant process operating in the riparian forest.

On the other hand, the South Platte River may still maintain enough hydrologic dynamism to enable continued cottonwood and willow recruitment, albeit in a smaller area than that covered by the historic narrowing episode (Friedman et al. 1997). Snyder and Miller (1991) found a slight increase in river channel width and loss of cottonwood forest area on the South Platte River in eastern Colorado between 1941 and 1979, based on aerial photograph analysis. They were optimistic about cottonwood recruitment, suggesting that it does still occur under the present hydrologic regime. Consistent with this idea, Johnson (1994) found that his two study sites on the South Platte River in Colorado exhibited a contrasting trend to those downstream: the Colorado sites showed trends of channel widening (increased active channel area) since the 1940's, and loss of riparian forest. Here, forest loss results from the erosion and sediment deposition necessary to create suitable sites for cottonwood recruitment, potentially enabling regeneration of the riparian forest.

USFWS / John Carr

The riparian forest on the South Platte River provides important wildlife habitat, as evidenced by the many Colorado State Wildlife Areas on the river in eastern Colorado.

Questions/Research Needs

Understanding the long term dynamics of the South Platte River riparian forest is critical to the management of this valuable natural resource. The riparian forest on the South Platte River provides important wildlife habitat, as evidenced by the many Colorado State Wildlife Areas on the river in eastern Colorado. On the other hand, evapotranspiration from this forest has been mentioned as a concern in the context of water resources management (Waskom 2013.: Nagler et al. (2010) review the current status of studies examining the potential for water salvage following phreatophyte removal and discuss the challenges to achieving water savings even if evapotranspiration is reduced.). Effective management of this forest requires an understanding of ongoing trends in forest area/extent and ecological succession. Although several studies addressed these questions in the past, new efforts are needed to update these prior studies. In particular, research is needed to assess long term trends in riparian forest spatial extent (i.e., loss and/or gain of forest area over time, and in association with specific flood events), dynamics of cottonwood regeneration, and successional trajectories of species composition within aging forest stands. This research will improve our understanding of the spatio-temporal dynamics of this riparian forest, and will provide an important context for management.

In particular, research is needed to assess long term trends in riparian forest spatial extent (i.e., loss and/or gain of forest area over time, and in association with specific flood events), dynamics of cottonwood regeneration, and successional trajectories of species composition within aging forest stands.

Matt Lavin

Peachleaf willow is a native, riparian pioneer species whose ecology is strongly linked to river-related disturbance processes and hydrology.

Within 10 m x 20 m plots located continuously along each transect, we collected data on tree abundance and condition, weed presence, and weed abundance.

South Platte Phreatophyte Survey

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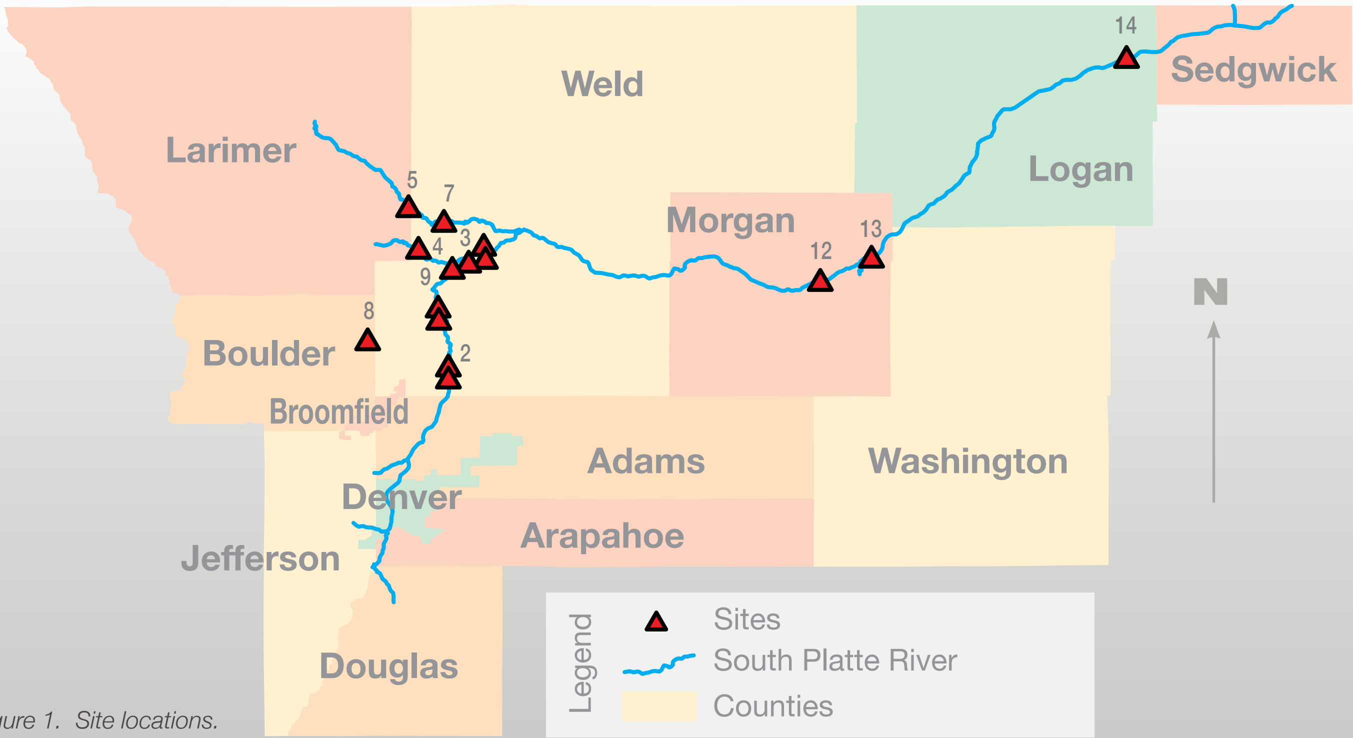


Figure 1. Site locations.

Introduction

This study focused on three different objectives 1) to determine the abundance and distribution of native and non-native woody phreatophyte species at twenty sites along the South Platte River, 2) to establish the relationship between shallow ground water and phreatophyte presence and abundance and 3) to determine the frequency and severity of invasion by Colorado State listed noxious weeds at these same sites.

Data Collection and Field Survey Results

Methods

We collected tree, shrub, and noxious weed presence and abundance data from 873 10 m x 20 m plots over 15 sites. Sites were selected to be representative of the study area and were distributed to along the South Platte and its tributaries. Within each site, 2–4 transects were selected at random and extended perpendicular to the river extending to the edge of the current floodplain. In most areas the historic floodplain has been constrained by human activities such as the construction of levees and roads. Within 10 m x 20 m plots located continuously along each transect, we collected data on tree abundance and condition, weed presence, and weed abundance. The sampling design and site locations are provided in Figures 2–4.

For each tree within each transect, we recorded diameter at breast height (dbh), the percent of the tree canopy estimated to be alive, and tree height. Height was measured with a laser range finder or a telescoping measuring rod. Trees were defined as individuals with dbh ≥ 2 cm. For tree saplings (individuals of tree species ≥1 m tall, but <2 cm dbh) and shrubs, we recorded basal diameter classes (<1 cm, 1—3 cm, >3 cm) and abundance. At many locations there were hundreds to thousands of shrub stems present within each 10 m x 20 m belt. In these cases, we subsampled several representative 1 m x 1 m areas and estimated total abundance by size class for an entire 10 m x 20 m plot. Tree seedlings (individuals of tree species < 1 m tall) were counted separately in basal diameter size classes as above. When more than 50 seedlings occurred within a 20 m x 20 m plot we estimated their number using the same methods as for saplings and shrubs.

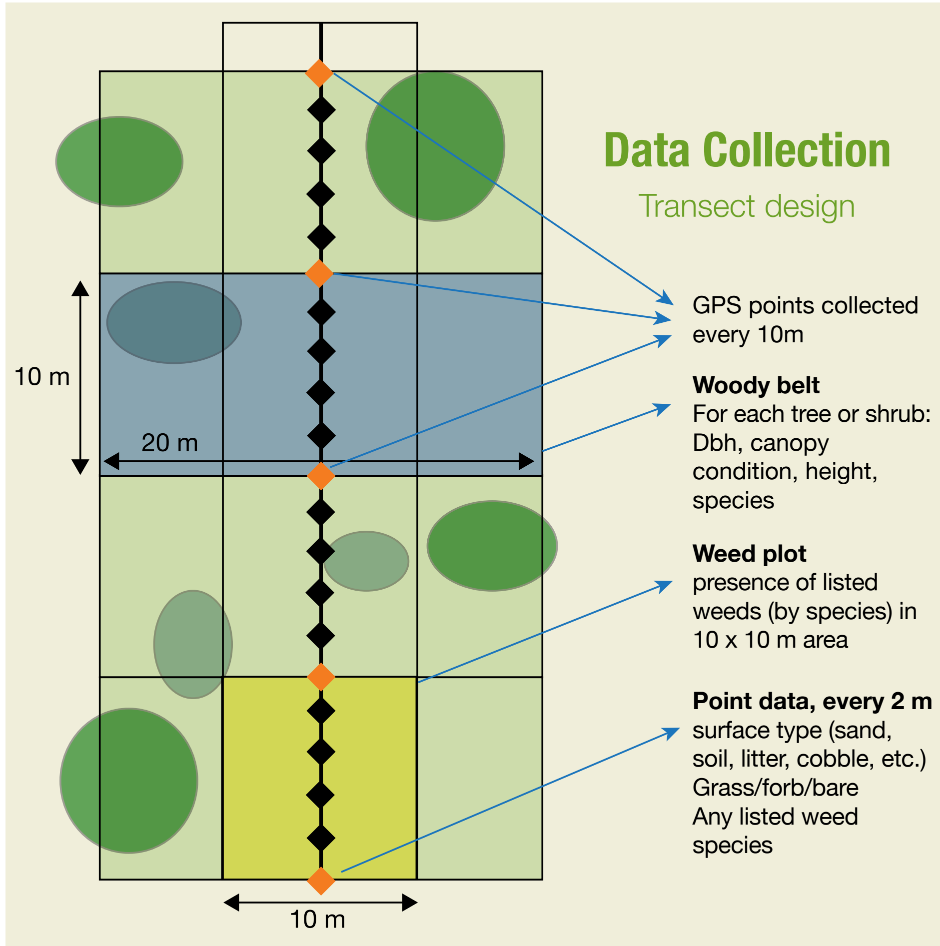


Figure 2. Transect sampling design. Transects are oriented perpendicular to the river at each site. Along the transects all tree and shrub species are measured within 10 x 20 m belts. Weed incidences are recorded every 2 m (point data) and within each 10 x 10 m block (incidence data). GPS coordinates are recorded every 10 m.

Figure 3. Example of transect sampling design from site 11. Yellow triangles are recorded GPS points taken every 10 m along transect.

We estimated the abundance of any state of Colorado listed weed species by collecting point data every 2 m along each transect. At each point, all listed weeds that touched a vertical measuring rod were recorded a present. In addition, the presence/absence of listed weeds was recorded in a 10 m x 10 m plot every 10 m along each transect. GPS coordinates were recorded every 10 m along each transect using a Trimble GeoXM and post-processed in TerraSync.

Results

We surveyed 873, 10 m x 20 m plots over 15 sites, for a total of 435 acres surveyed. Over all of these sites we collected dbh, height, and canopy condition data from 2182 trees.

Trees

As expected, plains cottonwood (*Populus deltoides*) is the dominant tree species in the South Platte floodplain, comprising more than 45% of the individuals recorded. Basal area (BA) is a common metric used to compare tree volume between sites, and is a measure of the total cross sectional area occupied by trunks. Just over 80% of the total tree basal area for the study area is comprised of plains cottonwood, followed in abundance by peachleaf willow (*Salix amygdaloides*) at nearly 12% of the total basal area. Species not native to Colorado comprise less 6% of basal area over all sites. The most common non-native tree species is Russian olive (*Elaeangus angustifolia*), which comprises 2.21 % of total basal area and 4.54 % of individuals encountered in the surveys.

Shrubs

Coyote willow (*Salix exigua*) was the dominant shrub species found, with approximately 83% of all stems recorded being from this species. Snowberry (*Symphoricarpos occidentalis*) was the next most abundant shrub species, with just over 14% of the total stems.

Saplings

There were far fewer saplings within the study area than trees, with a combined total of 386 saplings over all species over all sites. In contrast to the mature trees, green ash was the most common species of sapling recorded (131), followed by peachleaf willow (103). *Tamarix spp.* was the third most common sapling recorded, with 44, all of which were on a single sandbar at site 11 (Table 1). We suspect that these saplings all originated from one or two large, buried *Tamarix* trees. Although cottonwood is the most dominant tree species over all sites, we only recorded 43 sapling individuals, consistent with the idea that cottonwood recruitment requires a set of specific and relatively infrequent conditions in order for recruitment to occur.

Seedlings

Cottonwood seedlings were by far the most common tree seedling encountered, with more than 100,000 found over the entire survey area (Table 2). The number of cottonwood seedlings recorded was highly variable—ranging from 0 (site 1) to 32,936 at site 14. This variability likely results from the specific environmental requirements for cottonwood seed germination. Cottonwood seeds need bare, moist soil. Where these conditions occur, hundreds to thousands of seedling may germinate per m^2 We found a total of four seedlings of Russian olive, a surprising result given that this species is considered invasive in Colorado and that it is common (though not abundant) in the study area. We found 275 and 32 seedlings for Siberian elm (*Ulmus pumilla*) and *Tamarix* spp., respectively.

One of the questions raised, is to what degree cottonwood and willow are still reproducing within the study area. With altered flow regimes and channel narrowing, it is possible that these pioneer species are in decline and are being replaced by other species, most notably green ash, Russian olive, and Siberian elm. Figures 4a–f illustrate the size-class distribution of saplings and trees for the most common tree species in the area. Note that the single full growing season between the September 2013

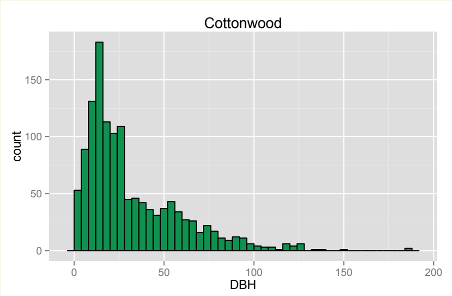


Figure 4a.

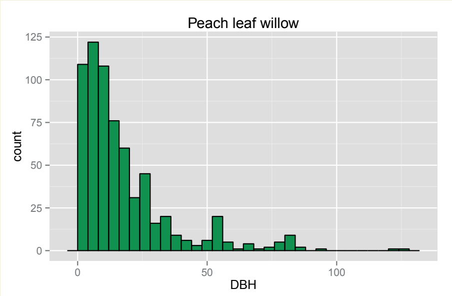
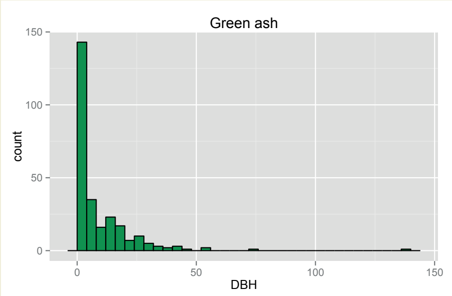


Figure 4b.



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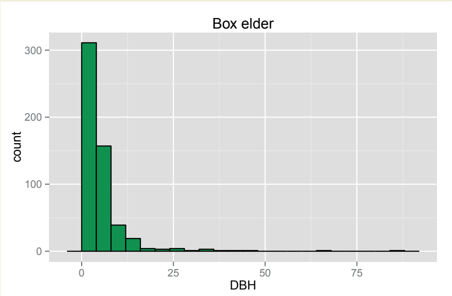

Figure 4d.

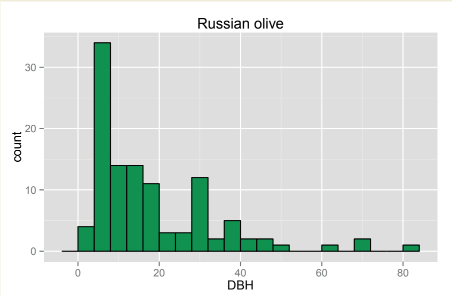

Figure 4e.

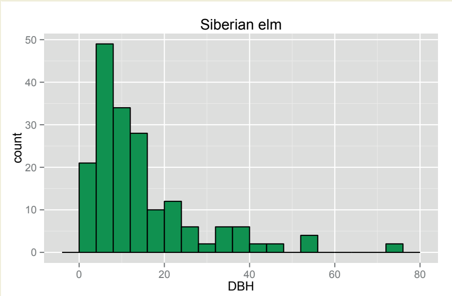

Figure 4f.

Figures 4a-f. Size distributions for trees in the study area. DBH represents the diameter at breast height (cm). Counts include saplings and mature trees.

flood and the summer 2015 data collection season is not a long enough period of time for a seedling to mature into a sapling. Thus, any seedlings germinated in summer 2014 or 2015 (post-2013 flood) would be counted as seedlings in our data.

If a species recruits at a constant rate, we would expect to see a monotonic decline in frequency of size classes for the species. Species with pronounced pulses of recruitment might exhibit a more 'bumpy' size-class histogram. Species that are no longer recruiting at a rate that will maintain population size will have a distribution with fewer smaller (younger) size classes than larger (older) size classes.

Cottonwood shows some evidence for this latter pattern, with a peak in the size class distribution at moderate dbh. However, it appears to be a recent phenomenon as only the two smallest size classes

Table 1. Summary of number of saplings by site.

Site	# plots	Hectare surveyed	American elm†	Box elder	Crack willow	Green ash†	Peachleaf willow	Plains cottonwood	Russian olive*†	Siberian elm*†	Tamarisk*†
1	46	9.2	0	0	0	0	0	0	0	0	0
2	24	4.8	0	0	0	1	8	4	0	1	0
3	67	13.4	0	0	0	0	0	0	0	0	0
4	48	9.6	0	0	0	0	1	0	0	0	0
5	47	9.4	0	0	0	0	0	0	0	0	0
6	47	9.4	0	0	0	0	9	0	0	0	0
7	59	11.8	0	0	0	0	2	0	0	0	0
8	48	9.6	0	0	0	0	1	9	0	2	0
9	65	13	0	0	0	0	14	0	0	1	0
10	63	12.7	0	30	0	1	18	10	9	0	0
11	112	22.4	0	2	0	0	0	1	0	0	44
12	46	9.3	0	1	0	0	10	4	1	0	0
13	61	12.2	0	0	0	96	0	6	0	0	0
14	84	16.86	0	2	0	33	7	4	0	0	0
15	56	11.2	0	1	0	0	33	5	0	14	0
Total	873	174.86	1	36	0	131	103	43	10	18	44
Percent of total, by species			.26	9.33	0.00	33.94	26.68	11.14	2.59	4.66	11.4

**Not native to North America †Not native to Colorado. Non-native column includes all species not native to Colorado.*

Table 2. Number of seedlings recorded for each tree species.

Site	# plots	Hectare surveyed	Box elder	Russian olive	Green ash	Cottonwood	Peachleaf willow	Tamarix sp.	American Elm	Siberian elm
1	46	9.2	0	0	1	0	0	0	0	0
2	24	4.8	0	0	4	5	3	0	0	4
3	67	13.4	0	3	0	328	1	29	0	2
4	48	9.6	0	0	0	17,777	90	3	0	0
5	47	9.4	55	0	5	1	35	0	0	71
6	47	9.4	0	0	0	25	12	0	0	0
7	59	11.8	0	0	3	19,961	72	0	0	0
8	48	9.6	0	0	4	6,388	1,029	0	0	125
9	65	13	0	1	0	23,560	58	0	0	1
10	63	12.7	39	0	98	39	17	0	0	4
11	112	22.4	0	0	18	153	0	0	0	0
12	46	9.3	0	0	33	1	7	0	0	3
13	61	12.2	1	0	3,226	350	26	0	5	0
14	84	16.86	0	0	1,125	32,936	0	0	0	0
15	56	11.2	1	0	18	63	28	0	3	65
Total	873	174.86	95	4	4,535	101,586	1,378	32	8	275

Andrew Norton

Within each site, 2–4 transects were selected at random and extended perpendicular to the river extending to the edge of the current floodplain.

(0–5 cm and 5–10 cm) are affected. Thus, it is possible that fewer smaller trees is simply the result of several years without flow patterns sufficient for seedling persistence. Siberian elm shows a similar pattern as well. In contrast, Russian olive and green ash do not have this pattern, and appear to have been recruiting at a constant or perhaps increasing rate through time. These data are size classes, which should correlate with tree age. However, the relationship between diameter and age differs for different tree species. Data on how diameter at breast height relates to tree age for each species would be very useful, but is beyond the scope of this project.

Weeds

State of Colorado listed noxious weeds were common at all sites. For example, nearly 30% of 10 m x 10 m plots surveyed contained hoary cress (*Cardaria draba*), and almost 35% of plots contained downy brome (*Bromus tectorum*). When all weed species are considered together, 90% of plots sampled contained one or more weed species. Percent cover for each weed species presents a similar picture. Over all plots and all sites, listed weeds make up more than 20% of plant cover. Downy brome (10.42%) and hoary cress (4.35%) are the most abundant weed species we found.

Discussion

Trees

As expected, cottonwood and willow are the dominant tree species throughout the study area, comprising more than 90% of the basal area over all sites. Although these two native phreatophytes are the most abundant mature trees, the relative absence of saplings and abundance of seedlings for the two species confirms that they have specific requirements for recruitment. In 2015, we found a large number of seedlings of these two species. The floods and high water of 2013, 2014, and 2015 likely created many bare, moist sites suitable for seedling germination. Whether these seedlings will be able to survive the next few years and become newly recruited saplings is an open question, as cottonwood seedlings typically experience very low survival rates. Contrary to expectations, non-native species make up a relatively small portion of the forest in the study area when compared to other western river systems. Additionally, there were few saplings and seedlings of these species. It seems unlikely at this point that the last few years of floods and high water have resulted in an outbreak of native or non-native tree species in the study area.

Weeds

State of Colorado listed weeds are common throughout the study area and are present at all sites. The most common species, downy brome, is in Colorado list "C". Species on this list are of concern, but do not require management action to prevent their continued spread. Common mullein is also on list C. One list "A" species, purple loosestrife, was found at two different sites. These species are designated for eradication within the state. All of the other weed species found are in Colorado list "B". Species on this list must be managed in a way to prevent their continued spread.

Working Toward Healthy Rivers, One Tree at a Time…

Children plant trees in Mesa County near the Colorado River.

Stacy Kolegas Beaugh, Executive Director, Tamarisk Coalition

When a child from an underprivileged community now has a place to play along the river, when a 4th generation rancher sees his land production and value increase, and when a young adult gets trained as a sawyer and herbicide applicator as part of her summer job, all as a result of tamarisk removal and river restoration activities, we know that we are doing our job. Tamarisk Coalition's mission is to help people manage invasive plants along riparian (riverside) lands and facilitate the restoration of these areas with native plants. The outcomes we see go beyond enhancing ecology; they support the growth of local economies, have positive social impacts, and position communities to take ownership over the rivers in their region.

Invasive plants such as tamarisk, Russian olive, Russian knapweed, and others can cause severe degradation and impairment to river systems as they aggressively displace native vegetation and compete for water resources, channelize river banks, reduce the quality of wildlife habitat and forage for pollinators, increase the risk of wildfires, and restrict access to scenic landscapes.

Tamarisk Coalition (2), envelopes: iStock.com

A Conservation Corps member removes Russian olive trees.

In the Colorado River Basin alone, mapped tamarisk accounts for a total stand acreage of approximately 250,000 acres of riparian lands. The U.S. Fish and Wildlife Service estimates that 80% of natural riparian habitat throughout the U.S. has been lost or altered in part due to the presence of invasive plants. The U.S. Congress estimates that invasive species have contributed to the decline of 42% of the threatened and endangered species in the U.S. and the annual cost to the U.S. economy is estimated at $120 billion a year, with over 100 million acres (an area the size of California) suffering from invasive plant infestations.

Founded in 2002, as a spin-off of a Grand Junction river clean-up project, Tamarisk Coalition is a non-profit organization dedicated to providing up-to-date technical information, education, and resources to advance the restoration of riparian lands. Our team, a board of nine and staff of twelve, works with communities, for communities. We support stakeholders who are conducting river restoration with a focus on invasive plant management in over fifteen different watersheds in the western portions of the U.S. The landscape-scale river restoration projects that we are typically involved in start and end with these stakeholder led partnerships—the local champions—including folks like Colorado Parks and Wildlife managers, City parks and public works staff, landowners, research institutions like Colorado State University, non-profit organizations, and concerned citizens that are passionate about seeing their rivers managed for invasive plants.

We have learned over the years that having dedicated partnerships and stewards within targeted watersheds are key to successful restoration over the long term. To help these groups accomplish their goals, we provide education and site planning support on how to treat tamarisk and other invasive plants—from helping to determine the effectiveness of a conservation corps sawyer crew versus a contractor with heavy machinery, to helping with prioritizing where work should occur and how much it will cost to meet specific partnership goals. In addition, we help partnerships identify short and long-term funding opportunities to support their work, and set up systems to ensure partnership sustainability into the future.

The U.S. Congress estimates that invasive species have contributed to the decline of 42% of the threatened and endangered species in the U.S. and the annual cost to the U.S. economy is estimated at $120 billion a year, with over 100 million acres (an area the size of California) suffering from invasive plant infestations.

The sustainability of these partnership groups not only translates to the health of their river but to strengthening their communities' economic and social condition. For example, the Dolores River Restoration Partnership, working in southwest Colorado and eastern Utah, employed 52 young adults and local contractors as they treated hundreds of acres of tamarisk and herbaceous weeds along the Dolores River corridor in 2015, investing $1.1 million into the rural communities served by the river. The Western Colorado Conservation Corps hired veterans for projects in the Grand Junction area; these veterans are instrumental in the restoration process, operating chainsaws, spraying herbicide, and rebuilding habitats for wildlife. The city of Grand Junction is helping kids access their own backyard river. The Middle Colorado Watershed Council is enhancing boating, fishing, and wildlife viewing access for the communities of Garfield County, which helps improve their quality of life and generate more tourism dollars.

As a regional organization, another role of ours is to connect restoration practitioners with those in the field that are conducting similar work in other watersheds. Our core forum for bridging this gap is an annual conference in which land and water managers, researchers, students, nonprofit organizations, government agencies, contractors, and others come together for two days to learn from each other and support one another as they take on similar, challenging projects to restore their riparian lands.

The next conference will be in Fort Collins, Colorado on February 7-9, 2017 where we expect close to 200 people from 17 states discussing issues ranging from the Colorado Water Plan, to the progress of the tamarisk beetle as a control tool, to how private businesses can support river restoration initiatives in the communities in which they work. We will hear a keynote speech from Clint Evans, the Natural Resources Conservation Service's Colorado State Conservationist, and host an interactive fundraising workshop to share expertise on grant writing, building and maintaining donor support, and other fundraising tactics.

Whether you are a recent college graduate wanting to network with people in the river restoration field, or a rancher that is looking for the latest technique to cost effectively rid your river of Russian olive, there is something for everyone to take away from the conference. By providing emerging technologies and information to inform best practices, we aim to empower people to be successful with their river restoration activities so they too can achieve outcomes that benefit their community.

We thank our generous sponsors for making our 15th annual conference possible—Colorado Water Conservation Board, the Walton Family Foundation, U.S. Bureau of Land Management, Chevron, U.S. Department of Agriculture Natural Resources Conservation Service, U.S. Fish and Wildlife Services Partners for Fish and Wildlife, Colorado Parks and Wildlife, Colorado Riverfront Foundation, Colorado State Forest Service, Colorado River District, Audubon Rockies, Colorado Legacy Coffee, REI, Many Rivers Brewing Company, and Avery Brewing.

To learn more about the Tamarisk Coalition's program and partners, or to register for the conference, visit www.tamariskcoalition.org, and be sure to sign up for our email list and like us on Facebook while you're on the web!

Using Remote Sensing Data for South Platte Phreatophyte Assessment

Data Acquisition and Preparation

Ahmed Eldeiry, Colorado State University

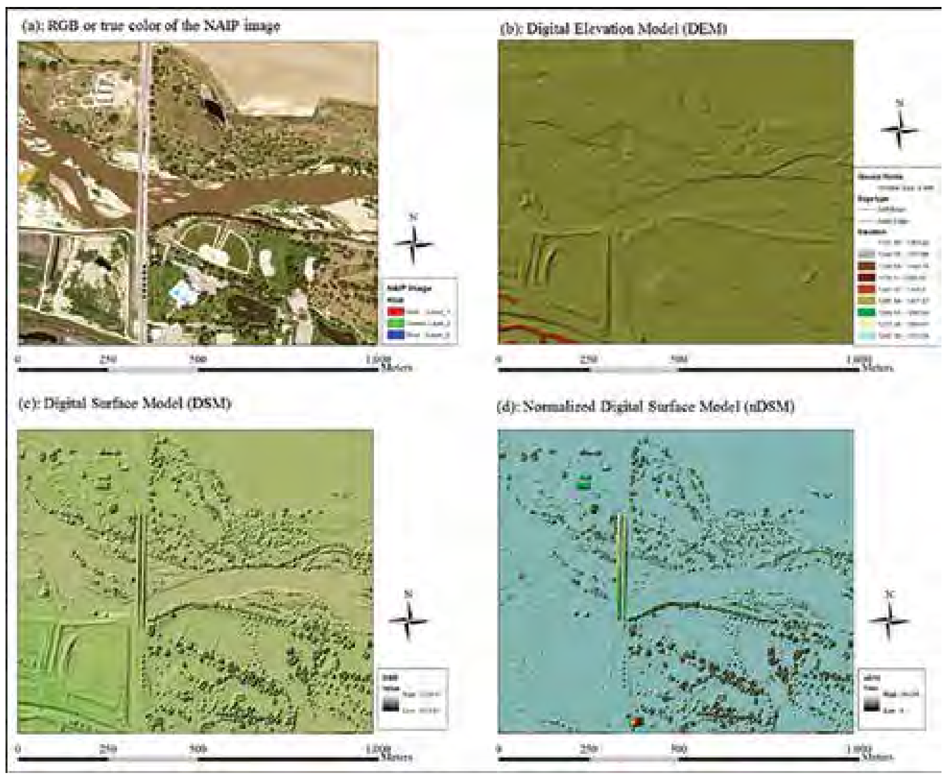

Figure 1a-d. Different surfaces generated from LiDAR datasets.

Remote sensing data from aerial imagery and LiDAR data are key elements in predicting the abundance of non-native phreatophytes and listed weeds along and within river systems. We used a combination of aerial imagery and LiDAR data to estimate phreatophyte species as well as identity tree mortality within the study area.

Aerial imagery was obtained from the National Agriculture Imagery Program (NAIP) These images contain four bands of color information (red, green, blue, and near infrared) and are produced with a 1 m ground resolution. The four bands of color information allow us to measure the Normalized Difference Vegetation Index (NDVI), which is used as a measure of how healthy vegetation is. Separate NDVI layers were generated for both 2013 and 2015. Images for both summer 2013 (pre-flood) and summer 2015 (post-flood) were acquired and processed in ArcGIS 10.1. Approximately 100 images that cover the study area were first combined into a single mosaic database. LiDAR data for the study area were acquired on October 25, 2013 and obtained from the United States Geological Survey (USGS) National Geospatial Program.

LiDAR remote sensing uses light pulses to measure surface elevation and texture. These data are acquired at approximately 60 cm intervals on the ground and can be processed into separate layers for ground elevation, (a Digital Elevation Model, also known as a DEM), and maximum elevation (for example the tops of vegetation—a Digital Surface Model, also known as a DSM). From these layers we can estimate vegetation height throughout the study area (a normalized Digital Surface Model, also referred to as a nDSM). LiDAR data were processed using ArcGIS 10.1's LAS Dataset tools to create 1 m horizontal resolution DEM, DSM and nDSM for the entire study area. Sample images of these layers are presented in Figures 1 a-d.

Estimating Tree Mortality

Methods

We developed a model to predict changes in tree abundance and health using a combination of vegetation height data derived from the LiDAR dataset and vegetation health data from the 2013 and 2015 NDVI estimates. To do this, we estimated for every portion of the study area with vegetation height greater than 2 m the change in NDVI from summer 2013 (pre-flood)

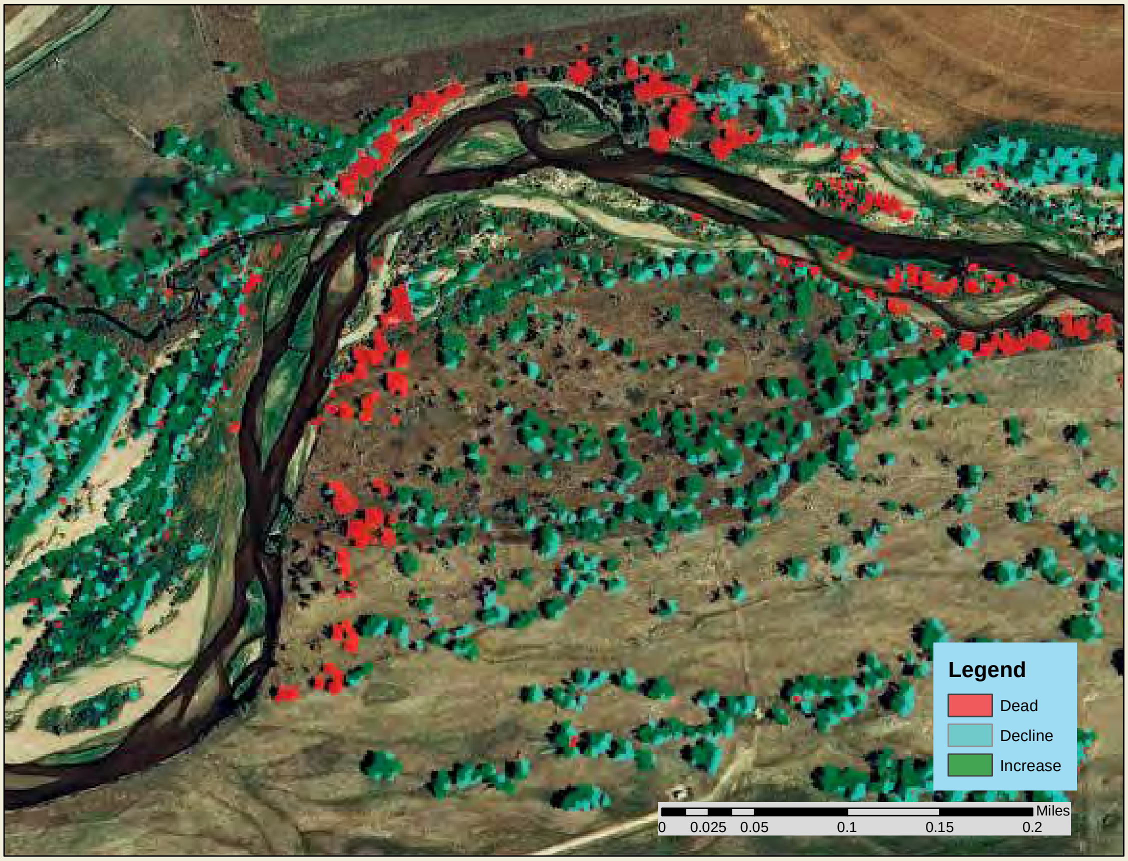

Figure 2a. Tree mortality estimated from LiDAR and remote imagery data. Background image is 2013 NAIP imagery.

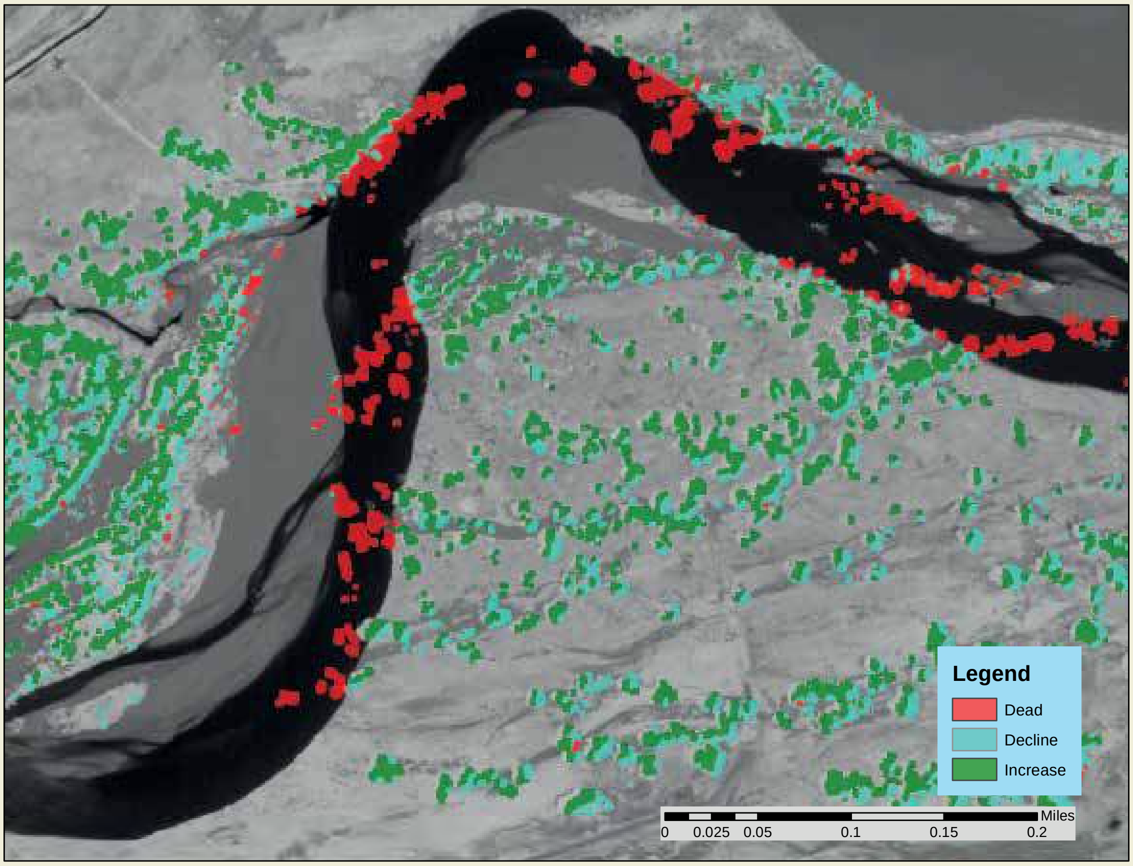

Figure 2b. This is the same portion of the study area as in 5a, but with 2015 NDVI as the base image. Note how the position of the river (dark pixels in this image) has changed relative to the 2013 image.

to summer 2015 (post 2013 flood and the high flow years of 2014 and 2015). Our process was to first select all portions of the study area with vegetation taller than 2 m and 2013 NDVI > 0.145. For these areas, we then calculated the difference in NDVI (d_NDVI) as NDVI 2015—NDVI 2013. By examining d_NDVI values for plots with dead or live trees from our survey data and from summer 2013 and summer 2015 imagery, we classified areas with trees as the following:

d_NDVI < -0.35 = dead or removed,
-0.35 < d_NDVI < -0.1 = declined
d_NDVI > 0.1 as increasing.

Results

In the interval between the October 2013 and July 2015, approximately 8.5% of the riparian forest was removed or died (Figure 2a-b). Visual examination of the output maps indicates that most of our estimated mortality is associated with the physical effects of the flood or from movement of the river channel. Less commonly, trees died that were some distance away from the 2013 or 2015 channel. In most cases, these areas are next to back channels or other low spots in the floodplain. Tree mortality was lowest for the South Platte River, upriver from its confluence with the St. Vrain, equaling 4.68%. 5.55% of the trees died on the South Platte between the St. Vrain and the Big Thompson and 5.19% between the Big Thompson and the Cache la Poudre. The tree mortality rate was highest on the St. Vrain (10.84%), followed by the South Platte downstream from its confluence with the Cache la Poudre (9.51%). These patterns are consistent with the pattern of flooding in 2013, with flooding occurring on the Cache la Poudre, Big Thompson, St. Vrain and moving into the main stem of the South Platte.

Discussion

It is difficult to unequivocally correlate our estimates of change in forest state to ground observations of tree mortality during the interval given the data we are able to collect. An ideal data set for this analysis would have ground observations of tree size and canopy condition in 2013 and again for the same locations in 2015. We do not have pre-flood ground data, and must rely on LiDAR just after the flood along with aerial imagery data from just before the flood to estimate the scope and condition of the pre-flood riparian forest.

Below are sources of error in our estimates of change in forest condition, and our estimates of how these might alter our conclusions on change in forest extent and status pre-2013 flood and post 2014 & 2015 high flow years:

1) Vegetation height data were generated from LiDAR data that were collected several weeks after the 2013 flood. Vegetation that was immediately uprooted by the 2013 flood and carried away are not included in our estimates. The effect of this is we are underestimating the magnitude of tree removal.
2) If a tree died or is removed, the difference in NDVI depends not only on how green the tree was in 2013 but also on what vegetation, if any, has replaced that tree. For example, for areas that were trees in 2013 and are now bare ground or active river, change in NDVI is very large. Bare ground and water have very low NDVI values. If a tree dies and there is now grass growing where the tree used to be, NDVI change is much smaller, as grass has an NDVI greater than bare ground, but still less than an actively growing tree. This leads us to underestimate the decline in riparian forest extent from 2013—2015 in areas where trees died from standing water, but where grasses and forbs were able to survive this or re-colonized the area between spring 2014 and spring 2015.
3) Variation in the spectral quality of NAIP images between years and for locations within years make it difficult to conclude that a small decline in NDVI represents a real change in vegetation quality or quantity, and is not simply a result of sampling noise. This requires us to use a more stringent cut-off for vegetation decline (tree death) instead measures of canopy decline and die-back. This underestimates the reduction in riparian forest.
4) The riparian forest could also have grown in response to the 2013 flood and 2014 and 2015 high water. Phreatophyte recruits (seedlings) that have been established since the floods are too small to be picked up by our remote sensing data (but see the survey data above). Remote sensing measurements of change in canopy volume are not possible without more recent LiDAR data. Even with more recent LiDAR data it would be difficult to separate change in forest extent or volume that is due to the flood from changes that occur every year as trees grow and reproduce. These act to overestimate the effect of the flood on forest decline.

Using Object Based Image Analysis (OBIA) to Estimate Different Tree Species:

OBIA uses unsupervised classification to partition an image into areas with similar data values. For this study, relevant data are the four bands of color information from the 2015 NAIP imagery, NDVI values from 2015 and nDSM values. OBIA is a computational intensive process. To speed up the process, we divided the study area into eleven reaches, each reach delimited by a river gauge. nDSM values were first filtered using ArcGIS's median and convolution filters with a 3 m x 3 m pixel size to minimize the effects of "spikes" in height data. The image of the study area was then segmented into polygons with similar data values using the software program eCognition. We then used a NDVI threshold of 0 to classify these polygons into vegetation, non-vegetation areas, and then a nDSM threshold of 2 m to classify vegetation into trees vs. other vegetation. Finally, we compiled imagery, NDVI, and nDSM data from polygons that occurred on top of our field plots where we had identified trees to species. These data were then used in a Decision Tree Classification program to create a rule set that classifies all tree polygons into one of three classes: Cottonwood, Russian olive, or other tree species. Attempts to classify polygons into more specific classes than these three were unsuccessful due to the spectral similarity between many of the tree species.

Results

Over the entire study area, 62% of trees were classified as Cottonwood, 10% as Russian olive and 28% as other. These values are higher than those estimated from the ground surveys. Basal area estimates (which correlate strongly with canopy area) from ground survey data were 80%, 2%, and 18% for these same species groups. Estimated classification accuracies for the segmentation process were 82%, 78%, and 61% for the Cottonwood, Russian olive and other tree species, respectively. Classification errors will result in overestimates for rare classes and underestimates of more common classes. For example, if 9% of Cottonwood trees are, on average, misclassified as Russian olive, a large section of forest that truly contains only Cottonwood would be expected to be classified as containing 9% Russian olive, 82% Cottonwood and 9% other tree species.

Using Regression Techniques to Estimate the Basal Area (BA)

The collected field data were regressed on the acquired LiDAR data in order to develop a BA map for the whole study area. The following are the steps of estimating the BA:

» The DBH data are measured for each tree in the plot samples (20 x 20 meter)

» The BA is calculated for each of the individual plots

» The corresponding plots are extracted from the LIDAR data using Fusion software

» A matrix was developed from the measured BA from the field data and the extracted LiDAR data

» LiDAR data used included canopy height variables such as: minimum., maximum, mean, mode, standard deviation, coefficient of variation, different percentiles from 1 to 99, and canopy density variables such as: 1st cover above mean, 1st cover above mode, 1st cover above 2 m, all cover above mean, all cover above mode, all cover above 2 m

Three different models were tested to determine the best methodology to estimate the BA including: 1) Ordinary Least Squares (OLS) using stepwise regression and model selection based on Akaike Information Criteria (AIC), 2) Multivariate Adaptave Regression (MARS), which is a non-parametric regression method that models multiple nonlinearities in data using hinge functions (functions with a kink in them), and 3) Decision tree (Random forest), an ensemble learning method for regression, that operates by constructing a multitude of decision trees at training time and outputting the class that is the mean prediction (regression) of the individual trees. Random forests correct for decision trees' habit of over-fitting to their training set. It grows a forest of many trees, each tree is a little different (slightly different data, different choice of predictors); and then combines the trees to get predictions for new data.

Remote sensing data of aerial imagery and LiDAR data are key elements in predicting the abundance of non-native phreatophytes and listed weeds along and within river systems.

William A. Cotton/CSU Photography

An aerial view of the Highland Ditch on the South Platte River southeast of Greeley, Colorado.

Senate Bill 14-195: Cost Estimate Summary

Shannon Hatch, Tamarisk Coalition

Background

Tamarisk Coalition (TC), in collaboration with Colorado State University (CSU), was tasked by the Colorado Water Conservation Board (CWCB) to develop cost estimates for the restoration of riparian areas impacted by invasive phreatophytes and associated secondary weed species in the South Platte Basin. Senate Bill 14-195 (SB195) was the enabling piece of legislation which established funds to: 1) study the effects of the 2013 flood on phreatophytes and 2) develop a cost analysis for the removal of unwanted phreatophytes along the South Platte River.

Utilizing CSU's geographic information system (GIS) based phreatophyte data, TC employed a "cost calculator" to determine approximate restoration costs for control and restoration work associated with the treatment of invasive phreatophytes. The riparian restoration cost calculator can be accessed via the Tamarisk Coalition's website at: http://www.tamariskcoalition.org/resource-center/documents/riparian-restoration-cost-calculator.

TC examined the cost of: 1) controlling 100% of all Russian olive (*Elaeagnus angustifolia*) infestations on each river reach, and 2) selectively thinning 20% of all trees from each river reach, including and prioritizing 100% of all Russian olive present. The methodologies and results from this work are described below.

Methods

TC developed the Cost Calculator to provide planners and managers with an estimate of expenses likely to be accrued during the management of invasive phreatophytes. While initial phreatophyte removal work is often thought of as the main project expense, costs for secondary weed control (herbaceous noxious weeds that may establish as a secondary invasion once woody phreatophytes are removed), phreatophyte resprout treatment, biomass reduction, revegetation, monitoring, and maintenance must also be considered to ensure appropriate funding and staffing resources for successful long-term management.

The Cost Calculator utilizes average canopy cover and total site acreage to determine an approximate project cost based on site specific recommendations, including: type of control, method of biomass reduction, specific amount of secondary weed control based on present densities, amount and type of grass seeding, and amount and type of shrub and tree plantings. Control and biomass reduction costs were developed by TC based on its local and regional experience with a variety of techniques and contractors. Revegetation costs for seeding were based on current market prices, provided by Pawnee Buttes Seed, Greeley, Colorado, while shrub plantings were based on costs provided by Los Lunas Plant Materials Center, Los Lunas, New Mexico. Please refer to *Methods for Tamarisk Control, Biomass Reduction and Revegetation* (Tamarisk Coalition, 2016) for additional information on various removal and restoration techniques, including the applicability of each methodology.

Cost-Calculator Usage

The following list defines the assumptions, appropriate uses, and limitations of TC's Cost Calculator. While every effort was made to ensure accuracy and relevancy of the tool, given the nature of resource management, it is difficult to account for all possible variables one may encounter while planning and/or implementing a project.

- Control costs are for actual on-the-ground work; they do not include any pre-planning or site visit costs. Control costs reflect average contractor charges to perform the work.
- Remote settings may incur additional costs not reflected in these estimates for mobilization, demobilization, employee housing/per diem, and time to access remote sites (e.g., backpacking, horseback, or rafting into a site).
- Site-specific conditions that may add costs include: grazing exclusion, traffic control, and permitting, are not included in these estimates.
- Equipment is assumed to be appropriately sized to meet the conditions encountered (e.g., for mechanical mulching equipment horsepower and cutting head size appropriate for density and/or trunk diameter).
- Each area that experiences control will require post-control monitoring and assessment to determine the degree to which revegetation will be required. Adaptive management is thus a key ingredient to successful restoration efforts.
- Herbaceous secondary weed management costs were based on the costs to treat Russian knapweed (*Acroptilon repens*), which can be a common secondary weed associated with phreatophyte removal. Cost estimates include three seasons of herbicide application to reduce Russian knapweed and any other major secondary weed infestation to less than 15% cover.
- The use of mechanical equipment, because of mobilization and demobilization costs, generally requires more sizable and contiguous infestations to warrant their use.

William A. Cotton/CSU Photography

An aerial view of the South Platte River near LaSalle, Colorado.

Table 1: Cost Estimate Scenarios						
	Scenarios					
	1	2	3	4	5	
Analysis	Phreatophytes — 90% Mechanical Removal with 10% Hand Removal					Maintenance
#1 – 100% Russian Olive removal (RO)	Removal only	w/50% Weed Control	w/25% Weed Control	w/25% Weed Control & Seeding	w/25% Weed Control & Seeding & Shrub Planting	Resprout control & revegetation 30%
#2 – 20% Total tree removal, including RO	Removal only	w/50% Weed Control	w/25% Weed Control	w/25% Weed Control & Seeding	w/25% Weed Control & Seeding & Shrub Planting	Resprout control & revegetation 25%

- The use of a combination of techniques for any one site will provide the best results for the least cost and should be chosen based on professional judgment.
- Other factors that may impact costs are land management desires such as using a site for training, education, and/or research-all of which can increase costs. Also, some landowners may restrict the use of vehicular access across their property to access public land; thus, adding to the overall costs.

South Platte Treatment Scenarios

Based on the goals of this project, TC performed two analyses to determine approximate treatment costs by river reach. In the first analysis, TC examined the cost of removing 100% of the Russian olive present within each of the river reaches. In the second analysis, TC determined the cost of treating a total of 20% of all trees within each reach, including removal of 100% of the Russian olive (Table 1). In pre-planning discussions a 20% tree removal objective was selected to use as an example for costs.

Since the total percentage of Russian olive did not exceed 20% along any of the reaches, the 20% removal target can include selective thinning of other trees, including invasive species such as tamarisk (*Tamarix* spp.), Siberian elm (*Ulmus pumila*) and in some instances, native phreatophytes that may be potentially considered too dense for site management objectives.

As the data provided by CSU grouped all trees, aside from Russian olive and cottonwood (*Populus* spp.), the 20% total tree removal target did not differentiate between other invasives and native phreatophytes. Furthermore, as the Cost Calculator was originally developed to determine costs for invasive tamarisk and Russian olive removal, not natives, the calculations for 20% total tree removal were solely based on treatment costs for Russian olive. While this does not change the cost for removal, it may slightly increase revegetation costs.

A total of five different management scenarios were examined for both analyses to provide a range of cost estimates for each reach (Table 1). In all scenarios, the recommended phreatophyte removal method was 90% mechanical removal, with 10% hand removal for areas difficult to access with equipment. Additional treatment and revegetation methods were then added on to this base cost.

Assumptions and Considerations for South Platte Treatment Sites

While the Cost Calculator can return myriad permutations, TC standardized the variables used for each analysis based on the assumptions and considerations outlined below.

- Access & Treatment Recommendations
    - ◊ Access to the various river reaches will not be an impediment (e.g. sites are not remote or located in difficult terrain), nor will the site contain large areas that are difficult to navigate with equipment.
    - ◊ Phreatophyte mechanical control is suggested as the primary control methodology (90%), with limited hand control (10%).
- Canopy Cover
    - ◊ For 100% Russian olive removal, canopy cover for Russian olive was listed at 100%, based on the number of impacted acres across the reach (e.g. if Russian olive was present on 10 acres, the average canopy cover was listed at 100% and the total site was entered at 10 acres).
    - ◊ For 20% total tree removal, canopy cover was listed at 20% and the total number of impacted acres was based on the "trees" acreage provided by CSU (e.g. if the total number of acres listed as trees for the reach was 100, 20% was used as the average canopy cover and the total site was listed at 100 acres).
        - Tree canopy cover was stated as Russian olive in the Cost Calculator to ensure consistency
    - ◊ While tamarisk canopy cover is listed as a data input option in the Cost Calculator, it was not utilized for any computation due to the vegetation data being grouped.
- Secondary Noxious Weeds
    - ◊ As State-listed noxious weed species were present within each of the river reaches examined, treatment of these species was included for various scenarios.
    - ◊ Site specific data were not used in the calculations due to the limitations of the Cost Calculator; rather, the scenarios were run at 0%, 25%, and 50% for areas infested with secondary weeds.
- Maintenance Costs
    - ◊ Costs for phreatophyte resprout control and revegetation establishment were included.
        - For 100% Russian olive control, maintenance costs were determined at 30%
        - For 20% tree control, maintenance costs were determined at 25%
- Revegetation
    - ◊ Some sites, especially those with a high percentage of invasives, may require additional seeding and/or planting of shrubs to reach site objectives.
    - ◊ Tree plantings were not recommended based on the expressed desire by some managers to reduce the amount of phreatophytes, invasive or native, currently

Table 2: Cost Estimates Based on Treatment Scenarios							
			90% Mechanical Treatment and 10% Hand Removal				
Treatment	Reach	Acres Russian Olive	Removal Only	Removal w/50% Weed Control	Removal w/25% Weed Control	Removal w/25% Weed Control & Seeding	Removal w/25% Weed Control & Seeding & Shrub Planting
#1 – 100% Russian Olive removal	1	19	$39,992	$44,932	$42,462	$54,961	$184,636
	2	3	$6,314	$7,094	$6,704	$8,579	$29,054
	3	8	$16,839	$18,919	$17,879	$22,878	$77,478
	4	16	$33,677	$37,837	$35,757	$45,756	$154,956
	5	474	$997,689	$1,120,929	$1,059,309	$1,355,535	$4,590,585
	6	527	$1,109,245	$1,246,265	$1,177,755	$1,507,728	$5,104,503
	7	19	$39,992	$44,932	$42,462	$54,961	$184,636
	8	71	$149,443	$167,903	$158,673	$203,669	$688,244
	9	40	$84,193	$94,593	$89,393	$114,391	$387,391
	10	490	$1,031,367	$1,158,767	$1,095,067	$1,401,292	$4,745,542
	11	7	$14,734	$16,554	$15,644	$20,643	$68,418
Total All Reaches			$3,523,485	$3,958,725	$3,741,105	$4,790,393	$16,215,443
Average All Reaches			$320,317	$359,884	$340,100	$435,490	$1,474,131
#2 – 20% Total tree removal, including Russian Olive	1	1095	$594,777	$868,527	$731,652	$1,390,252	$2,827,439
	2	37	$20,097	$29,347	$24,722	$47,557	$96,120
	3	257	$139,596	$203,846	$171,721	$326,756	$664,069
	4	471	$255,835	$373,585	$314,710	$598,341	$1,216,529
	5	3897	$2,116,753	$3,091,003	$2,603,878	$4,946,235	$10,061,047
	6	3136	$1,771,533	$2,586,983	$2,179,213	$4,139,053	$8,419,693
	7	515	$279,735	$408,485	$344,110	$654,181	$1,330,118
	8	1326	$749,060	$1,093,820	$921,440	$1,750,122	$3,560,112
	9	616	$347,980	$508,140	$428,060	$813,028	$1,653,868
	10	5667	$3,201,300	$4,674,720	$3,938,010	$7,480,221	$15,215,676
	11	186	$101,031	$147,531	$124,281	$236,050	$480,175
Total All Reaches			$9,577,697	$13,985,987	$11,781,797	$22,381,796	$45,524,846
Average All Reaches			$870,700	$1,271,453	$1,071,072	$2,034,709	$4,138,622

present in these reaches post-flood.

◊ A suite of South Platte specific species for seeding was developed by Pawnee Butte Seeds in Greeley, Colorado.

- Pawnee Buttes provided costs for both drill and broadcast seeding, all costs were determined in the Cost Calculator using the broadcast rates.

◊ CWCB developed an Access database that should be of use in planning for revegetation needs. This database can be accessed at the CWCB's website at: http://cwcb.state.co.us/environment/watershed-protection-restoration/Pages/main.aspx.

Results

Table 2 provides the cost estimate for the scenarios described above. For 100% Russian olive removal, costs range from an average of $320,317 for removal only to $1,474,131 for removal with weed control, seeding and shrub planting; total costs for all reaches range from $3,523,485 for removal only to $16,215,443 for removal with weed control, seeding and shrub planting.

For 20% total tree removal, costs range from an average of $9,577,697 for removal only to $4,138,622 for removal with weed control, seeding and shrub planting; total costs for all reaches range from $9,577,697 for removal only to $45,524,846 for removal with weed control, seeding and shrub planting.

Summary of SB 14-195 Findings and Recommendations

Andrew Norton, Department of Bioagricultural Sciences and Pest Management, Colorado State University
Reagan Waskom, Director, Colorado Water Institute
Gabrielle Katz, Assistant Professor, Department of Earth and Atmospheric Sciences, Metropolitan State University of Denver

Forest composition and future trajectory

» Riparian forest composition and extent in the South Platte basin have likely been under continuous change since water development began in the mid-19th Century. This process is driven by both short- and long-term patterns of river discharge within the system. Maintenance of cottonwood and willow forests depends upon periodic flooding and disturbance patterns that allow for both seedling establishment and long-term survival.

» The riparian forest along the South Platte River is dominated by Plains cottonwood, in terms of basal area, stem density, and canopy cover. The second most common mature tree species is the Peach-leaf willow.

» Currently, the most common non-native phreatophytes in the study area are Russian olive and Siberian elm. We estimate that non-native phreatophytes make up between 4% and 10% of the riparian forest on a per-area basis.

» The issue of whether removing phreatophytes increases water supply has been studied for many years, and little empirical evidence exists that tree removal will sustainably increase water supply.

Effects of flooding on Phreatophytes

» A conservative estimate of the result of scouring, erosion, and/or temporary inundation from the 2013 flood and subsequent high water years in 2014 and 2015 is that at least 8.5% of the forest, on an area basis, died in this interval.

» The flood opened up new areas for cottonwood seedling germination and establishment that occurred during 2014 and 2015. We do not yet know whether these seedlings will survive to become saplings or mature trees.

Cost of Phreatophyte Control

» Estimated total costs for removing 20% of phreatophytes from all reaches range from $870,700 for one-time removal only, to $45,524,846 for removal plus weed control, seeding, and shrub planting.

Recommendations

» Additional monitoring will be needed to assess long-term trends in riparian forest spatial extent, dynamics of cottonwood regeneration, and successional trajectories for species composition within aging forest stands. A key question that remains is how frequently cottonwood seedlings successfully recruit to the sapling stage within this system.

» Understanding both the historical trajectory of cottonwood recruitment, and the effects of the last three years of flood and high water on recruitment, would allow us to better predict the long-term trajectory of the forest. This study provides an important data point in time characterizing the riparian forest in the lower South Platte basin in 2015. It is recommended that this data be secured, and that the South Platte Roundtable determine a recurrence interval on the order of 3 to 5 years to update the data, allowing more accurate understanding of the state and trajectory of the riparian forest.

» Phreatophyte removal efforts — if pursued — should concentrate on the non-native phreatophytes in the system. Native species, such as cottonwood and willow, appear to be declining without intervention.

» Removal efforts — if pursued — need to include appropriate re-vegetation strategies that promote the maintenance of desirable native species, while preventing further expansion of noxious weed species.

William A. Cotton/CSU Photography

An aerial view of the Springdale Ditch on the South Platte River, Atwood, Colorado.

Andrew Norton

Professor, Department of Bioagricultural Sciences and Pest Management, Colorado State University

I joined the faculty in the Department of Bioagricultural Sciences and Pest Management at Colorado State University in 2000. At CSU my research program is centered on Pest Ecology and Management. This gives me a diverse set of problems and study systems to work on.

I received my Bachelor's degree from the University of California Santa Cruz and my PhD in Entomology from the University of California Berkeley. My research focuses on developing more efficient and sustainable methods for managing pests in agricultural production systems and natural areas. I approach my research by using the tools and techniques from basic ecology to understand how a system works, and then use this information to provide practical solutions for pest and management problems.

When I started at CSU, I focused on invasive plant species, addressing how to use biological control to manage these plants. Biological control is the use of living organisms to manage the populations or impact of another species. One of the reasons non-native plant species become more abundant when introduced to a new range is that they leave behind many of the insects and diseases that feed on them. In their new range, invasive species are free to grow and reproduce without these 'natural enemies', an advantage that native plants do not possess. Biological control seeks to identify the organisms that limit these species in their original range, find those that will only feed on the introduced weed species, and then introduce these species to restore natural control of the pest.

The competitive environments that plants face vary across the landscape. The impact of biological controls varies across the landscape as well. Understanding how resource availability shapes plant

Andrew Norton

performance and biocontrol agent abundance and impact can guide us in the selection of those species that are likely to have the greatest impact. For example, biological controls of diffuse knapweed have no significant effect on plant performance when the weed is grown without competing vegetation. When grown in competition with a native grass, biological controls reduced plant performance by more than 50%.

Another focal area of my research has been to evaluate the impact of non-native species and their associated management techniques on native plants and ecosystem services. One example is a project on measuring the impacts of Russian olive on soil nitrogen (N), available light and plant community composition along the Republican River in eastern Colorado. Russian olive is a nitrogen-fixing species, and areas around this tree have 2–3 fold greater plant available N than areas without the tree. The tree also has a canopy that is denser and intercepts more light than species native to the area. This results in a shift in the plant community away from native perennial grasses towards one dominated by annual weedy grasses and forbs. Most of these weedy species are not native to North America. Unfortunately, mechanical removal of Russian olive does not cause the plant community to revert back to its un-invaded state: High soil N remains for at least a few years, and possibly much longer, after removal of the tree.

In addition to research, I also teach undergraduate and graduate level courses. One of the undergraduate courses I teach is Plants and Civilizations, a course focused on understanding the diverse relationships between plants and humans through time and across cultures. This course helps first-year students gain critical thinking and communication skills. One week we may discuss why, when where and how humans first started to get the majority of food from agriculture, the next it could be banana domestication and its impact on colonialism and global trade. Working with first-year college students is challenging, but extremely rewarding. Watching students develop their critical thinking and communication skills over the course of the semester is the best part of my job.

Andrew Norton

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Water Research Awards 9/1/16—12/12/16

Arabi, Mazdak, Kansas State University, iCrop Decision Support Tool, $70,092

Arabi, Mazdak, U.S. Department of Agriculture, Agricultural Research Service, Modeling Ecosystem Services in Agricultural Watersheds, $70,000

Bailey Ryan, T., Water and Environmental Systems Technology, Inc., Measuring Pumping-Induced Streamflow Depletion, $49,572

Bailey, Ryan, T., West Greeley Conservation District, Groundwater Pumping Pilot Study for Gilcrest, $8,050

Culver, Denise, R., Environmental Protection Agency, Tools for CO Wetlands—Phase Four, $109,186

Culver, Denise, R., Environmental Protection Agency, Survey and Assessment of Critical Wetlands in Lake County, CO, $91,834

Doesken, Nolan, J., U.S. Department of Agriculture, U.S. Forest Service, Rocky Mountain Research Station, Description of the historical and current climate of the Rio Grande National Forest area, $10,000

Doesken, Nolan, J., Colorado Water Conservation Board, Expanding an agricultural meteorological network for improved crop water use estimation in the Upper Colorado River Basin, $44,297

Doesken, Nolan, J., Colorado Water Conservation Board, Colorado Mesonet Project (FY2017), $149,999

Evangelista, Paul, H., Walton Family Foundation, Mapping and Monitoring Invasive Species in Riparian Habitats of the Colorado River Basin, $229,947

Gomez, Douglas, M., Department of Defense, Army Corps of Engineers, Evaluation of Herpetofauna Population Response to Habitat Types at Chief Joseph Dam Project and Wildlife Sites, Rocky Mountains Cooperative Ecosystem Studies Unit, $55,954

Herron, Christopher Michael, Department of Defense, Army Corps of Engineers Omaha, Preble's Meadow Jumping Mouse Habitat Restoration, $306,398

Ippolito, Jim, Binational Agricultural Research and Development Fund, Phosphorus Capture, Recycling and Utilization for Sustainable Agriculture and a Clean Environment Using Al/Organic Composite Water Treatment Residuals, $91,720

Johnson, Lynn Eugene, Department of Commerce, National Oceanic and Atmospheric Administration, Assimilation of Lake and Reservoir Levels into the WRF-Hydro National Water Model to Improve Operational Hydrologic Predictions, $50,000

Jones, Kelly, W., National Science Foundation, The Role of Citizen Science in Watershed Hydrology Research and Policymaking: Relationships Between Volunteer Motivation, Data Quality, and Model Reliability, $47,170

Liston, Glen, E., National Science Foundation, Collaborative Research: Snow, Wind, and Time: Understanding Snow Redistribution and its Effects on Sea Ice Mass Balance, $212,551

Morrison, Ryan Richard, Department of the Interior, U.S. Geological Survey, Ecological Impacts of Hydroscape Modifications, $75,000

Nagel, Linda, M., U.S. Department of Agriculture, U.S. Forest Service, Rocky Mountain Research Station, Colorado, Rio Grande National Forest Climate Change and Planning Collaboration, $25,000

Schipanski, Meagan Erin, U.S. Department of Agriculture, Agricultural Research Service, Develop Knowledge for the Efficacy of Using Cover Crops in Place of Summer Fallow in Dryland Wheat-Fallow Cropping, $20,000

Simpson, Rodney Thomas, National Ecological Observatory Network, Laboratory Services Agreement for Water Chemistry Laboratory Analysis, $394,655

Waskom, Reagan, M., Walton Family Foundation, Colorado River Basin Policy with Emphasis on Upper Colorado River Contingency Planning, $246,350

Wohl, Ellen, E., National Geographic Society, Toward a Quantitative Estimate of Organic Carbon Storage in River Corridors of the United States, $5,943

USGS Publications

Characterization and relation of precipitation streamflow, and water quality data at the U.S. Army Garrison Fort Carson and Piñon Canyon Maneuver Site, Colorado, water years 2013–14, 2016, U.S. Geological Survey Scientific Investigations Report 2016–5145, p. 58, M.J. Holmberg, R.W. Stogner Sr., J.F. Bruce,

Groundwater and surface-water interaction, water quality, and processes affecting loads of dissolved solids, selenium, and uranium in Fountain Creek, Pueblo County, Colorado, 2012–2014, U.S. Geological Survey Scientific Investigation Report 2016–5134, U.S. Geological Survey Scientific Investigation Report 2016–5134, p. 78, L.R. Arnold, R.F. Ortiz, C.R. Brown, K.R. Watts

Ion-adsorption REEs in regolith of the Liberty Hill pluton, South Carolina, USA: An effect of hydrothermal alteration, 2016, Journal of Geochemical Exploration, v. 172, p. 29-40, C.R. Bern, T. Yesavege, N.K, Foley

Water Calendar

January

25 **Colorado Water and Emergency Services Coordination Workshop; Brighton, CO**

The Environmental Protection Agency presents a workshop for organizations involved in extreme weather event management, including presentations from water utilities and emergency management agencies.

http://www.dhsem.state.co.us/prevention-security/training/water-utility-and-emergency-services-coordination-workshop

25-27 **Annual Colorado Water Congress Convention; Denver, CO**

The Colorado Water Congress Annual Convention is the premier water industry event in the state, attracting 500+ attendees that convene for networking and collaboration on the important water issues of the day.

http://www.cowatercongress.org/annual-convention.html

March

14-16 **2017 IGSHPA Technical/Research Conference and Expo; Denver, Co**

Ground source heat pump industry conference and exposition with workshops featuring GeoExhange design and GeoThermal Inspection.

http://www.igshpa.okstate.edu/conf/

20-22 **2017 Utah Water Users Workshop; St. George, UT**

In cooperation with the State of Utah, U.S. Government, Utah Farm Bureau Federation, and USU Extension Service.

http://conference.usu.edu/uwuw/

21-23 **Hydrology Days and iWater Symposium; Fort Collins, Co**

Sessions include water management, hydrology, groundwater, climate, hydraulics, erosion, and sustainability.

http://hydrologydays.colostate.edu/HDsProgram_2016.html

22 **World Water Day: "Water Shed" Film; Fort Collins, Co**

View a film screening of "Water Shed: Exploring a New Water Ethic for the New West" in the CSU Behavioral Sciences Building Room 131 to Celebrate World Water Day.

http://hydrologydays.colostate.edu/Abstracts_16/Watershed-Film.pdf

April

7 **2017 Annual Water Seminar: Southwestern Water Conservation District; Durango, CO**

A broad range of topics will be covered in the 35th Annual Water Seminar, including the various local projects that have been funded by the district's grant program.

http://swwcd.org/programs/annual-water-seminar

20-22 **2017 Federal Water Issues Conference; Washington, D.C.**

National Water Resources Association presents Federal Water Issues.

http://www.nwra.org/upcoming-conferences-workshops.html

30-5/3 **2017 Spring AWRA Conference; Snowbird, UT**

Connecting the Dots: The Emerging Science of Aquatic System Connectivity.

http://www.awra.org/meetings/Snowbird2017/

June

3 **Poudre Riverfest; Fort Collins, CO**

Poudre RiverFest is a free, family-friendly festival in Fort Collins, Colorado, that restores, celebrates and educates people about the Cache la Poudre River, an important natural resource in our community. The festival features a variety of activities for people to explore the role of the river as an important habitat for wildlife, a recreation area and a source for clean drinking water.

http://www.poudreriverfest.org/about-the-festival/

12-15 **2017 UCOWR/NIWR Conference; Colorado State University; Fort Collins, CO**

http://www.ucowr.org/conferences/2017-ucowr-conference

August

22-25 **Colorado Water Congress Summer Conference and Membership Meeting**

The high-energy Summer Conference is packed with great topical content. It's a don't miss event for those who wish to stay informed about water issues in Colorado while engaging in numerous professional development activities.

http://www.cowatercongress.org/summer-conference.html

For more events, visit www.watercenter.colostate.edu.

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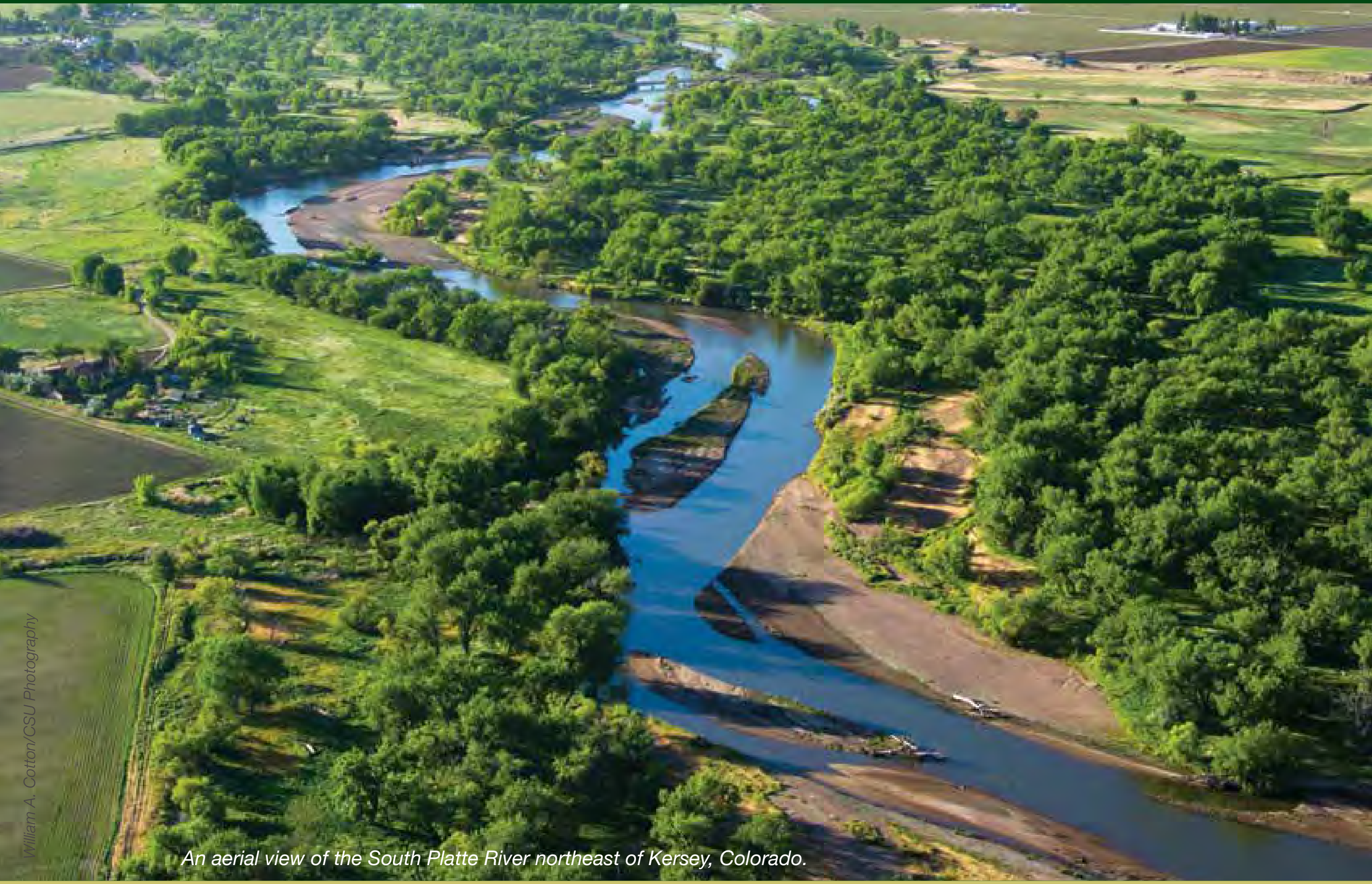

William A. Cotton/CSU Photography

An aerial view of the South Platte River northeast of Kersey, Colorado.