

PLANT COMMUNITY RESPONSE TO TAMARISK INVASION AND HYDROLOGIC
REGIME IN THE CATARACT CANYON, CANYONLANDS NATIONAL PARK:
A PRELIMINARY INVESTIGATION

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Summary

In the southwestern US, the composition and abundance of riparian plants has changed as a result of flow regime alteration and the invasion of *Tamarix*. We investigated trends in vegetation dynamics along the Green and Colorado Rivers in Canyonlands National Park (CNP) from 1976 to 2008 through historical aerial photo analyses. We also explored the relationships between understory and overstory species in riparian habitat of CNP. The effects of river regulation on seedling establishment patterns were assessed in slightly regulated, moderately regulated, and extremely regulated river sections in the southwestern US.

Tamarix dominated the overstory vegetation in all river sections in CNP but was less dominant along the Colorado (73% vs. 83%-86% for the Green and Cataract sections). Overstory-understory relationships were generally quite weak, although species commonly found with *Tamarix* included *Bromus tectorum*, *Distichlis spicata*, and *Sporobolus* spp. Seedlings of *Tamarix* and *Salix exigua* were abundant, with the latter being far more abundant than below the Glen Canyon Dam in Grand Canyon. However, seedlings of *Populus fremontii* and *Salix gooddingii* were rare. Apparent differences in the affinities of *Tamarix* and *Salix exigua* for certain soil characteristics including pH, conductivity, and relative concentration of ammonium are difficult to interpret without complementary experimental studies.

The results from the historical aerial photo analysis suggest that riparian vegetation composition in CNP has been stable, although the aerial extent of riparian vegetation increased from 1976 to 2008. Large floods in the early 1980s caused decreases in the average patch size of most species, particularly *Tamarix*. *Salix exigua* patches have increased at the highest rate in the last 30 years most likely because of the ability to reproduce clonally.

Despite a surprisingly high level of stability over the past 40 years, riparian overstory vegetation in CNP may change dramatically as a result of the recent introduction of the saltcedar leaf beetle. It is therefore imperative that other non-native invasive species be prevented from filling the gap that may be created by defoliated and severely weakened *Tamarix*. Park Service efforts to remove *Elaeagnus* have apparently been successful, as live individuals of this species were observed on only 5% of random floating transects, all along the Green River. Similarly, it would be beneficial to encourage native woody species that can outcompete *Tamarix*. Our observations suggest that *Tamarix* cover is lowest where cover of *Acer negundo* is highest, along the Colorado upriver from the confluence. We recommend that CNP focus on monitoring and removal of *Elaeagnus*, and experiment with planting of *A. negundo* in *Tamarix* patches that have been defoliated by the saltcedar leaf beetle along the Colorado River.

Introduction

In the past century, changes in hydrologic regimes caused by climate change and river regulation have affected the composition and abundance of riparian woody plants in the southwestern US. At the same time the invasion of non-native plants such as *Tamarix*, *Elaeagnus angustifolia* (Russian olive), *Centaurea repens* (Russian knapweed), and *Lepidium latifolium* (perennial pepperweed) has changed the competitive dynamics of riparian communities. Invasive plants can outcompete native species and alter environmental characteristics such that riparian habitat is no longer suitable for natives (Vitousek 1990). For example, large stands of *Tamarix* can accumulate sediment and contribute to channel narrowing (Graf 1978). Channel narrowing is often associated with decreased water table levels and can cause mortality of native phreatophytes (plants rooted just above the water table). Although

riparian plants are adapted to dynamic environments, the long-term response of plant populations to changing flow, climatic, and competitive regimes remain uncertain.

Riparian vegetation has evolved with frequent disturbances associated with floods (scour, burial, inundation). Riparian species have life history characteristics that enable them to avoid, withstand, or recolonize during or following floods. For example, some woody species can resprout from roots and emerge quickly following removal of above-ground biomass (e.g., *Salix exigua*). Phreatophytes have deep roots that help them anchor and withstand the forces of floods. Many species in the family Salicaceae (*Populus fremontii*, *S. exigua*) have strong resprouting ability and flexible stems that allow them to withstand floods with high shear stress (Karrenberg et al. 2002).

In the southwestern US plants have adapted to flow regimes characterized by snowmelt-driven floods that occur in the early spring. Many of these species such as *P. fremontii* (cottonwood) and *Salix gooddingii* (Goodding willow) have life history characteristics that are strongly tied to flow regimes (Scott et al. 1997; Shafroth et al. 1998), and alterations in hydrologic regimes can inhibit establishment and change successional trajectories (Fenner et al. 1985; Rood & Mahoney 1990; Shafroth et al. 2002). *Populus fremontii* and *S. gooddingii* release seeds during the time of historic average flood recession when bare areas are typically available for establishment. Dam construction in the southwestern US has generally shifted the time of annual floods to later in the year, and the magnitude of these floods has decreased. Dams have blocked fine sediment which is needed for establishment of early successional species. Fires have increased in frequency due to human error and increases in riparian vegetation, particularly *Tamarix* (Webb et al. 2007).

This project was designed to assess the long-term dynamics of riparian plant communities in Canyonlands National Park (CNP) along the Green and Colorado Rivers. We focused on *Tamarix* because this species has been spreading through riparian habitat in CNP since 1925 (Graf 1978) and has become the most abundant riparian woody plant. Recent releases of the saltcedar leaf beetle along the Green and Colorado Rivers have initiated cycles of *Tamarix* defoliation and may eventually result in the mortality of large *Tamarix* stands. Collectively, the information gleaned from this research should provide the Park with spatially-explicit baseline data to measure the effects of the imminent arrival of the saltcedar leaf beetle.

We compared current vegetation composition of the Green, Colorado, and Cataract Canyon river sections and conducted an aerial photo analysis of historical changes in woody vegetation. These studies differ from previous historical oblique studies of riparian vegetation due the ability to quantify establishment, growth, and mortality of riparian plant community types. Understory species (grasses, forbs, and legumes) are not detectable in aerial photographs but have likely responded to the hydrologic changes and *Tamarix* invasion. Therefore, we explored the relationships between understory species and overstory woody species in riparian habitat of CNP. We assessed the effects of river regulation on seedling establishment patterns in reaches that are slightly regulated (Colorado above confluence), moderately regulated (Green) and extremely regulated (Colorado in Grand Canyon National Park). With knowledge of the conditions that favor seed germination and establishment, managers should be able to target locations for removal of non-native seedlings and, perhaps, implement restoration of native vegetation in appropriate sites following repeated *Tamarix* defoliation by the saltcedar leaf beetle.

Study Area

The Green and Colorado Rivers converge within the boundaries of Canyonlands National Park and flow through Cataract Canyon before reaching Lake Powell (Figure 1). The slow-flowing stretch of the Green River known as Stillwater Canyon has been regulated by the Flaming Gorge Dam since 1962. This dam has reduced peak flood discharges and sediment in downstream reaches, but the relatively unregulated Yampa and White Rivers mediate effects of the dam (Webb et al. 2007). The Colorado River upstream from the confluence is also slow-flowing. This is the least regulated stretch of the Colorado River although dams on the Gunnison and Dolores tributaries have reduced peak flows and sediment supply (Webb et al. 2007). Cataract Canyon is a narrow, constrained section of the Colorado River. Riparian vegetation is more sparse here than in upstream sections. Large floods occurred in CNP during 1983 and 1984 (Figures 2 & 3). High flows also occurred along the Colorado River in 1993 (Figure 2).

Methods

We conducted a research river trip in three river sections in CNP (Colorado, Green, Cataract Canyon) during October 18-24, 2008 to address the current distribution and abundance of woody species, historic vegetation dynamics, characteristics of current germination sites, and associations among understory and overstory plants. We formed two teams that launched at Mineral Bottom (Green) and Potash (Colorado) and then convened at the confluence. Water levels were approximately $62.3 \text{ m}^3\text{s}^{-1}$ ($2,200 \text{ ft}^3\text{s}^{-1}$) on the Green and $124.6 \text{ m}^3\text{s}^{-1}$ ($4,400 \text{ ft}^3\text{s}^{-1}$) on the Colorado.

Historic changes in woody vegetation

We mapped woody vegetation at fourteen large (~1 km long) sites for use in a historical aerial photo analysis. Sites were selected based on the availability of historical aerial photos with minimal shadows and ease of recognition. Three sites on both the Colorado and Green Rivers and eight sites in Cataract Canyon were mapped that totaled 66.8 ha (165 acres). Because riparian vegetation patches along the Green and Colorado Rivers upstream of the confluence are continuous bands, patches were delineated according to dominant overstory vegetation. The percent canopy cover of riparian woody species was visually estimated within each patch. The elevation of each patch above the water level was determined through the combination of field surveys with a rod and transit and a 5-m digital elevation model. The average elevation was summarized for each patch. The approximate height of each overstory species and average soil texture within each patch were also measured.

We conducted an aerial photo analysis of historical vegetation change with a series of historical aerial photos from 1976, 1984, 1995, and 2002 of the fourteen large mapping sites (excluding 1984 for which photos of Bonita Bend, Gooseneck, and Upheaval were unavailable) (Table 1). These photos were orthorectified using 2006 NAIP orthophotos (1-m resolution) and ArcGIS software. Patches that were delineated in the field were digitized on rectified photos from each of the five years. Patches of similar vegetative composition (the same dominant overstory species) were lumped to reveal temporal and spatial patterns of riparian plant community types. We compared current vegetation composition of the Green, Colorado, and Cataract Canyon rivers. Changes in relative patch composition within sites were compared among the three river corridors through time. We also related changes in patch size to hydrologic and precipitation records.

Understory associations

Forbs and grasses were identified and cover was estimated by Daubenmire cover classes within and on the edges of each patch. The associations between understory species that were frequently sampled (≥ 10 occurrences) and dominant overstory species were assessed using Jaccard's coefficient of community (Legendre & Legendre 1998). We also explored potential relationships between understory composition and elevation above the channel, overstory cover, and height of dominant overstory species.

Seedling habitat analyses

We conducted 80 random seedling surveys to investigate current germination patterns of *Tamarix* and other common woody species (*S. exigua*, *P. fremontii*, and *S. gooddingii*). Random sites were selected for surveys of 20-m transects parallel to the river. Site locations and spatial precision were documented with GPS units. We searched for seedlings in the riparian zone and collected soils from the germination surface where seedlings were present. The density and height of seedlings was noted, and photographs were taken of each site.

We hoped to identify characteristics of germination sites for native and non-native woody plants. Soil texture, electrical conductivity (a measure of salinity), pH, and nitrogen content were analyzed in the USDA-ARS soils lab in Reno, NV. We separated coarse particles (>0.1 mm) from sand (<0.1 mm & >0.063 mm) and fine sediment (clay + silt) (<0.063 mm) using dry sieves that were shaken for three minutes to determine soil texture. After adding 1 mL of calcium chloride and 20 mL of deionized water to 5 mL of soil we measured pH with a pH meter. To measure conductivity, soil was saturated and centrifuged for 5 minutes at 5000 rpm.

The excess liquid was measured with a VWR EC meter. Potassium chloride (KCL) extractions were performed to estimate nitrate and ammonium. KCL (1.5 molar) was added to ten grams of soil. The vials were then agitated and centrifuged. The remaining liquid was analyzed with a Lachat Quik-Chem FIA++ machine.

ANOVA tests with Bonferroni-corrected multiple comparisons were used to compare soil characteristics among rivers. We used logistic regression models to assess probability of *Tamarix* and *S. exigua* seedling occurrence in relation to soil characteristics. Akaike's information criterion (AIC) were used to compare the best-fit models (see Burnham & Anderson 2002). Lower AIC scores indicate better fit models, particularly when there is a difference of at least two AIC units. These results were compared with results from a similar seedling / soil study in the Colorado River through Grand Canyon in Spring and Fall of 2007.

Floating transects

We estimated the number of individual plants of *Tamarix*, *P. fremontii*, *Elaeagnus*, *A. negundo*, *Fraxinus*, and *Celtis* on the Green and Cataract sections in 98, 100-m "floating transects" to quantify the distribution of these species outside of the large mapping sites. The GPS location of the starting point of each transect were documented.

Results

General trends

Tamarix dominated the overstory vegetation in all river sections (Green = 86%, Cataract = 83%) but was less dominant along the Colorado (73%) (Figure 4). Damage caused by the saltcedar leaf beetle was observed in a patchy distribution along all river sections but was most

evident along the Green River. We observed defoliated *Tamarix* as far downstream as Rapid 12. The majority of *Tamarix* individuals that had been defoliated during the growing season were growing new leaves. Seventeen overstory species were mapped (Table 2). *Populus fremontii* and *S. gooddingii* were not mapped at sampling sites but were present along the Colorado. *Salix amygdaloides* was present at the Confluence and Sheep Bottom. *Elaeagnus* was not present at mapping sites but was documented on the Green River in five floating transects. *Acer negundo* was not observed on the Green River. *Celtis* was mapped only in Cataract Canyon but was observed in one floating transect along the Green River. *Rhus* was present along all river sections but was only abundant in Cataract Canyon (Figure 4). Many sites along the Green and Colorado exhibited signs of recent fire (Gooseneck, Loop, Upheaval, and Sheep Bottom). Spanish Bottom was burned in 2007, so our mapping of this site is based on post-fire remnant vegetation.

Historic changes in woody vegetation

At sites sampled along the Colorado and Green Rivers the aerial extent of riparian vegetation increased at a steady rate from 1976 to 2008 (Figure 5). Between 1976 and 1995 riparian vegetation cover decreased in Cataract Canyon but then increased steadily. However, the relative composition of riparian species remained constant along the Colorado (Figure 6), Green (Figure 7), and Cataract Canyon (Figure 8). *Salix exigua* appeared to increase steadily along the Green River and Cataract Canyon. The relative cover of *Tamarix* and *Rhus* decreased along the Green River from 1976 to 1995 while *S. exigua* and *Forestiera* increased (Figure 7).

No major establishment events were revealed through the aerial photo analysis. Only 41 out of 267 patches established during the time periods analyzed (Table 3); the remaining 226

patches established prior to 1976 and have persisted. Most new patch establishment events have occurred in Cataract Canyon (28 of 41 patches established since 1976). The average patch size of *Celtis*, *Forestiera*, *P. fremontii*, and *Tamarix* decreased from 1976 to 1995 (Figure 9). *Tamarix* experienced the greatest reduction in patch size during this period (Figures 9 & 10). The analysis that included the 1984 photos showed similar trends but with a smaller sample size (Figure 10). However, *S. gooddingii* patch size decreased from 1976 to 1984 in these patches. Excluding the decreased patch size from 1976 to 1995, *Forestiera* patch size increased at a low rate. *Celtis* patches showed no net change in patch size from 1976 to 2008. Some *Tamarix* patches decreased from 2002 to 2008 (particularly in Cataract Canyon). *Salix exigua* had the greatest increase in average patch size from 1976 to 2008 (Figure 9).

Seedling habitat analyses

The percent of seedling survey sites that contained *S. exigua* and *Tamarix* seedlings did not differ between the Green, Colorado, and Cataract Canyon sections (Table 4). However, survey sites in the Grand Canyon had significantly fewer sites with *S. exigua* seedlings. There was no difference in nitrate (NO₃), total nitrogen, and conductivity (EC) at sites in CNP and GCNP (Table 4). Ammonium (NH₄) was significantly higher in Cataract Canyon than Grand Canyon. In the Grand Canyon pH was significantly lower than sites in CNP, and sites along the Green River had higher pH than along the Colorado. Coarse particles along the Green River were lower than in Cataract Canyon. Sand-sized particles were lower and fine particles were higher along the Colorado than in the Grand Canyon and Green (Table 5).

Regression models with AIC comparisons revealed relationships between *Tamarix* and *S. exigua* seedling presence and soil characteristics for sites within CNP. The best-fit model for *S.*

exigua included pH (negative effect) and nitrate (positive effect), and the best-fit model for *Tamarix* included nitrate and ammonium (positive effects). The relative importance of nitrate, ammonium, and fine sediments was similar for *S. exigua* and *Tamarix* (Table 6). However, low values of pH were highly influential in models of *S. exigua* presence. Conductivity (EC) and the percent of nitrogen in the form of ammonium were influential variables in *Tamarix* models but not *S. exigua* models.

Understory

Sixty-five understory genera were sampled (Table 2). One species (*Eragrostis hypnoides*) had not been documented previously in CNP. Native *Cyperus erythrorhizos* (redroot flat-sedge) was abundant near the river in sites where *Tamarix* seedlings were also abundant. All sampling sites along the Colorado (Gooseneck, Sheep Bottom, Loop) contained *Bassia*, a problematic invader. *Centaurea repens* was growing at two sites along the Green and Cataract. Due to the late season of this survey, the identification of *Lepidium* species was difficult, but *Lepidium latifolium*, an invasive *Lepidium* species, was found along the Green and in Cataract Canyon. *Xanthium strumarium* (cocklebur) and *Cyperus erythrorhizos* (redroot flat-sedge) were present in patches that were lower in elevation (Figure 11) and had a lower average overstory canopy cover (Figure 12) and height (Figure 13).

There were few clear associations between overstory and understory species, but Jaccard's coefficient of community revealed that some understory species were more constrained by overstory composition than others (Table 7). *Bromus tectorum*, *Machaeranthera canescens*, and *Suaeda torryana* were found frequently in *P. fremontii* patches. *Cyperus erythrorhizos* and *Xanthium strumarium* were found more often in *S. exigua* patches. *Sarcobatus vermiculatus*

patches often contained *Bassia*. *Bromus tectorum*, *Distichlis spicata*, and *Sporobolus* spp. were more frequent in *Tamarix* patches.

Discussion

Tamarix appears to be less dominant along the Colorado due to prevalence of *A. negundo* in this section (Figure 4), particularly at the Loop. Stands of *A. negundo* are capable of limiting *Tamarix* establishment through shading (Dewine & Cooper 2008). The small area occupied by *P. fremontii* patches likely prevents this tall-statured species from limiting *Tamarix* abundance along the Green River. The decrease over time in relative cover of *Tamarix* along the Green River (Figure 7) is the result of site-specific factors. The relative cover of *S. exigua* increased at two sites (Bonita Bend & Upheaval), and *Forestiera* increased at River Mile 12 from 1976 to 1995. Additionally, a large *Tamarix* patch at River Mile 12 eroded between 1995 and 2002. Sampling of additional sites is necessary to confirm that these patterns are representative of these three major river sections.

The overall increase in riparian vegetation cover from 1976 to 2008 corresponds with channel narrowing that has been attributed to climate change, river regulation, and *Tamarix* dominance (Webb et al. 2007). Using repeat series of historical oblique photographs Webb et al. (2007) observed decreases in *P. fremontii* and increases in *Tamarix*, *S. exigua*, and *Celtis* abundance along the Green and Colorado. In our study *Tamarix* and *S. exigua* increased in patch size from 1976 to 2008. The overall increase in *P. fremontii* relative cover and patch size from 1976 to 2008 and lack of change in *Celtis* patch size are inconsistent with Webb et al. (2007). However, our study focuses on a more recent time period unlike Webb's analyses that often span a century.

Riparian vegetation decreased between 1976 and 1995 in Cataract Canyon but increased along the Green and Colorado. The constrained nature of Cataract Canyon produced greater scouring forces during the large floods in the early 1980s. *Salix exigua* and *S. gooddingii* patches increased from 1976 to 1995 likely due to high flood tolerance and resprouting ability (Karrenberg et al. 2002). Other species that reproduce from seed take longer to recover from the floods (e.g., *Tamarix*, *P. fremontii*). *Sarcobatus* and *A. negundo* grow at higher elevation sites that are protected from flooding and, therefore, did not experience decreases in patch size from the 1980s floods. High rainfall during the 1999 and 2001 growing seasons (Figure 14) allowed increases in patch sizes of all overstory species excluding *S. gooddingii* which decreased at the Bonita Bend site. Low rainfall from 2002 to 2008 may have contributed to reduced patch growth of *A. negundo*, *Celtis*, *P. fremontii*, and *Sarcobatus*. High flows also occurred during 2004 (Figures 2 & 3) that may be responsible for minor decreases in *Tamarix* patch size in Cataract Canyon.

The results from the historical aerial photo analysis suggest that riparian vegetation in CNP has been stable from 1976 to 2008. Very few patches experienced total mortality, and relatively few patches (41 of 267; 15%) established during this time period (Table 3). This is especially surprising after the large floods in the 1980s. Cabezas et al. (2009) also observed high stability of mature vegetation types along the Ebro River in Spain, even following a 60-year flood. The high vegetation density that established in the early 20th Century on many rivers of the western United States stabilized river banks so that even large floods could not damage vegetation (Shafroth et al. 2002). The 1984 aerial photos revealed that remnants of most vegetation patches remained following the floods. These biotic legacies (*sensu* Turner & Dale 1998) facilitated rapid recolonization and allowed patches to persist over time.

Regulated reaches of the Verde River in Arizona have less nitrate, phosphorus, silts, and clays than unregulated reaches (Beauchamp & Stromberg 2008). Our study revealed lower nitrate levels along the regulated Colorado through Grand Canyon and Green Rivers (Table 5). The relatively unregulated Colorado in CNP had significantly higher percentages of fine sediments than the Green and Grand Canyon. The high pH levels of soil along the Green may indicate low levels of available phosphorus. Many of the soil characteristics were not significantly different among river sections. The small sample size (Cataract) and conservative statistical tests used contributed to this, but there is also a lot of inherent variation in microsites of riparian areas. The lower frequency of *S. exigua* seedlings in the Grand Canyon (Table 4) is likely caused by hydrologic parameters (e.g., lack of flooding) and high salinity (Table 5).

Plant-soil relationships in the riparian zone are complex due to the interaction of hydrology with chemical and biological processes and sediment characteristics. The affinity of *S. exigua* and *Tamarix* seedlings for soils with high nitrate (Table 6) could result from the combination of nutrient requirements and the effects of frequent inundation on soil nutrient cycling. In wet, oxic soils organic nitrogen is most often converted to nitrate which creates high nitrate to ammonium ratios. In anoxic soils, denitrification is common which reduces nitrate levels (Marschner 1995). Flooded soils can inhibit germination, accumulate toxins, and reduce root growth, even in flood-adapted species such as *Tamarix* and *S. exigua* (Kozlowski 1984). Soils with high pH values may be less likely to support *S. exigua* seedlings because of their physiological intolerance of bicarbonates or lower phosphorus availability in high pH soils (Marschner 1995). *Tamarix* is more tolerant of high salinity conditions than *S. gooddingii*, *P. fremontii*, and other common riparian species (Glenn et al. 1998), and this may contribute to higher EC levels in sites where *Tamarix* seedlings were surveyed in CNP.

The general lack of association between overstory and understory species is not surprising because, in semi-arid riparian systems, water availability is the primary factor controlling herbaceous species richness (Lite et al. 2005). For example, the association of *Cyperus erythrorhizos* and *Xanthium strumarium* with *S. exigua* is a result of these species occurring in low elevation sites. *Tamarix* and *Bromus tectorum* often co-occurred in this study which has been observed in other areas (Simberloff & Von Holle 1999). However, *Bromus tectorum* was also common in *P. fremontii* patches. We found no trend in the elevation of non-native understory species (Figure 11) unlike Bagstad et al. (2006) who observed more non-native species near the water. There is a combination of upland (*Salsola tragus* and *Bromus tectorum*) and lowland (*Xanthium strumarium*) invaders in CNP. Although many understory species occurred along the edge of patches, the average overstory canopy cover was high (Figure 12). This likely corresponds with the timing of this survey (the end of the dry season) when herbaceous species tend to have higher diversity under patches with higher canopy cover. This trend was reversed along the San Pedro River during the wet season, with more open patches having higher understory diversity (Lite et al. 2005).

Management Implications

Recommendations for Restoration

1. We recommend that CNP continue to focus on monitoring and removal of *Elaeagnus angustifolia* (Russian-olive). The paucity of *Elaeagnus* in CNP is surprising, especially considering the high cover of this species in Green River and Moab, UT (pers. obs.). National Park Service (NPS) weed teams and river rangers have removed *Elaeagnus* from sites along the river (M. Moran, pers. com.), and these efforts should be continued

indefinitely. If *Elaeagnus* is allowed to gain a foothold in CNP, this species will proliferate and may colonize *Tamarix* stands that have been decimated by the saltcedar leaf beetle. Early detection of potential invaders is the most effective way to control invasive species (Hobbs & Humphries 1995). Vigilant monitoring and removal of *Elaeagnus* along with other nascent invaders (e.g., *Lepidium latifolium* and *Centaurea repens*) should be a top priority for NPS personnel.

2. Similarly, it would be beneficial to encourage native woody species that can outcompete *Tamarix*. Our observations suggest that *Tamarix* cover is lowest where cover of *Acer negundo* (box-elder) is highest, along the Colorado upriver from the confluence. Recent experiments suggest that *A. negundo* is a potential replacement species for *Tamarix*; *A.* seedlings establish readily under *Tamarix* canopies along the Green River in Dinosaur National Monument (DeWine & Cooper 2009). We recommend that CNP plant *A. negundo* in *Tamarix* patches that have been defoliated by the saltcedar leaf beetle along the Colorado River.
3. Despite large flood events in the mid-1980s, riparian vegetation in CNP has been surprisingly stable for over 30 years at the 14 large “bottoms” for which the historical analysis was conducted. Few new patches of riparian vegetation have been initiated, vegetation patches recovered rapidly *in situ* from the floods, and patch expansion during the flood-free periods has been fairly slow. This apparent stability has the potential to change in the very near future, however, due to two disturbance agents: the saltcedar leaf beetle and a high frequency of wildfire. More than at any time during the previous several decades, the CNP resource management staff has the opportunity to facilitate a conversion of the riparian plant community away from dominant *Tamarix* and toward

native species. Due to the high resilience of *Tamarix* and the availability of other aggressive, exotic plants, this shift will likely not occur with passive restoration. It will be necessary to actively clear *Tamarix* where it has been weakened by fire and beetles, and to plant native species that can outcompete *Tamarix* over the long term.

Recommendations for Research

1. We suggest field experiments to test the ability of various, tall-statured native woody riparian species (e.g. *A. negundo*, *S. gooddingii*, *P. fremontii*) to outcompete *Tamarix* that has been weakened by the saltcedar beetle, in an active restoration context involving planting seedlings in appropriate microsites.
2. Given the current flow regime, there are many microsites that are suitable for germination of *S. exigua* seedlings; planting of this species seems unnecessary. However, our surveys revealed few *P. fremontii* and *S. gooddingii* seedlings. More research is needed to identify the characteristics of sites that foster *P. fremontii* and *S. gooddingii* establishment in CNP. We recommend a combination of observational studies and field experiments involving transplanting seedlings.
3. The understory data represent only one season, and many of the grasses and forbs were dry and difficult to identify. Patterns of herbaceous species richness change according to dry and wet season (Lite et al. 2005, Bagstad et al. 2006), and surveys during spring are needed to assess associations between wet season plants and overstory vegetation. Understory surveys in spring would most likely result in documentation of additional species in CNP.

References

- Bagstad, K. J., S.J. Lite, & J.C. Stromberg. (2006) Vegetation, soils, and hydrogeomorphology of riparian patch types of a dryland river. *Western North American Naturalist* 66: 23-44.
- Burnham, K.P. & D.R. Anderson. (2002) Model selection and multimodel inference: a practical information-theoretic approach, Second Edition. Springer-Verlag, New York, NY.
- Cabezas, A., F.A. Comín, S. Beguería, & M Trabucchi. (2009) Hydrologic and landscape changes in the Middle Ebro River (NE Spain): implications for restoration and management. *Hydrology and Earth System Sciences* 13: 273-284.
- DeWine, J.M. & D.J. Cooper. (2008) Canopy shade and the successional replacement of tamarisk by native box elder. *Journal of Applied Ecology* 45: 505-514.
- DeWine, J.M. & D.J. Cooper. (2009) Habitat overlap and facilitation in tamarisk and box elder stands: implications for tamarisk control using native plants. *Restoration Ecology* January early view: 1-10.
- Fenner, P., W.W. Brady & D.R. Patton. (1985) Effects of regulated water flows on regeneration of Fremont cottonwood. *Journal of Range Management* 38: 135-138.
- Glenn, E., R. Turner, S. Mendez, T. Kehret, D. Moore, J. Garcia, & C. Valdes. (1998) Growth rates, salt tolerance, and water use characteristics of native and invasive riparian plants from the delta of the Colorado River, Mexico. *Journal of Arid Environments* 40: 281-294.
- Graf, W. L. (1978) Fluvial adjustments to the spread of tamarisk in the Colorado Plateau region. *Geological Society of America Bulletin* 89: 1491-1501.
- Hobbs, R. J., & S.E. Humphries. 1995. An integrated approach to the ecology and management of plant invasions. *Conservation Biology* 9:761–770.
- Karrenberg, S., P.J. Edwards, & J. Kollman. (2002). The life history of Salicaceae living in the active zone of floodplains. *Freshwater Biology* 47: 733-748.
- Kozlowski, T.T. (1984) Plant Responses to Flooding of Soil. *BioScience* 34: 162-167.
- Legendre, P. & L. Legendre. (1998) *Numerical Ecology*. Elsevier, Amsterdam, Netherlands.
- Lite, S.J., K.J. Bagstad, & J.C. Stromberg. (2005) Riparian plant species richness along lateral and longitudinal gradients of water stress and flood disturbance, San Pedro River, Arizona, USA. *Journal of Arid Environments* 63: 785-813.
- Marschner, H. (1995) *Mineral Nutrition of Higher Plants*, Second Edition. Academic Press, London, UK.
- Rood, S.B., & J.M. Mahoney. (1990) Collapse of riparian poplar forests downstream from dams in western prairies: probable causes and prospects for mitigation. *Environmental Management* 14: 451-464.
- Scott, M.L., G.T. Auble, & J.M. Friedman. (1997) Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. *Ecological Applications* 7: 677-690.
- Shafroth, P.B., G.T. Auble, J.C. Stromberg, & D.T. Patten. (1998) Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. *Wetlands* 18: 577-590.
- Shafroth, P.B., J.C. Stromberg, & D.T. Patten. (2002) Riparian vegetation response to altered disturbance and stress regimes. *Ecological Applications* 12: 107-123.

- Simberloff, D. & B. Von Holle. (1999) Positive interactions of nonindigenous species: invasional meltdown? *Biological Invasions* 1: 21–32.
- Turner, M.G. & V.H. Dale. (1998) Large, infrequent disturbances: what have we learned? *Ecosystems* 1: 493-496.
- Vitousek, P.M. (1990) Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. *Oikos* 57: 7-13.
- Webb, R.H., J. Belnap, & J.S. Weisheit. (2004) *Cataract Canyon: A Human and Environmental History of the Rivers in Canyonlands*. The University of Utah Press, Salt Lake City, UT.
- Webb, R.H., Leake, S.A., & Turner, R.M. (2007) *The Ribbon of Green: Change in Riparian Vegetation in the Southwestern United States*. The University of Arizona Press, Tucson, AZ.

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Tables and Figures

Table 1. Historical aerial photo properties.

Date	Scale	Agency	CO flow (m ³ s ⁻¹)	Green flow (m ³ s ⁻¹)
August 1, 1976	1:6,000	CNP	54.65	81.27
July 6, 1984	1:29,000	USGS	991.09	419.09
June 27, 1995	1:24,000	CNP	965.60	736.24
June 25, 2002	1:12,000	CNP	44.74	41.91
July 13, 2006	orthophotos	NAIP	205.30	77.59

Table 2. Overstory and understory species sampled. Asterices indicate non-native species.

Abbreviation	Species	Common name	Family
<i>Overstory:</i>			
ACENEG	<i>Acer negundo</i>	box elder	Aceraceae
ATRCAN	<i>Atriplex canescens</i>	four-wing saltbush	Chenopodiaceae
ATRCAN	<i>Atriplex confertifolia</i>	shadscale	Chenopodiaceae
BACSAL	<i>Baccharis salicina</i>	willow baccharis	Asteraceae
BRILON	<i>Brickellia longifolia</i>	longleaf brickellbush	Asteraceae
CELRET	<i>Celtis laevigata</i>	netleaf hackberry	Ulmaceae
CHRNAU	<i>Chrysothamnus nauseosus</i>	rabbitbrush	Asteraceae
FORPUB	<i>Forestiera pubescens</i>	desert olive	Oleaceae
FRAANO	<i>Fraxinus anomola</i>	singleleaf ash	Oleaceae
GUTSAR	<i>Gutierrezia sarothrae</i>	broom snakeweed	Asteraceae
POPFRE	<i>Populus fremontii</i>	Fremont cottonwood	Salicaceae
RHUTRI	<i>Rhus trilobata</i>	skunkbush	Anacardiaceae
SALAMY	<i>Salix amygdaloides</i>	peachleaf willow	Salicaceae
SALEXI	<i>Salix exigua</i>	coyote willow	Salicaceae
SALGOO	<i>Salix gooddingii</i>	black willow	Salicaceae
SARVER	<i>Sarcobatus vermiculatus</i>	greasewood	Chenopodiaceae
TAMSP*	<i>Tamarix</i> sp.	saltcedar; tamarisk	Tamaricaceae
<i>Understory:</i>			
AMASP	<i>Amaranthus</i> sp.	pigweed	Amaranthaceae
AMBACA	<i>Ambrosia acanthicarpa</i>	ragweed	Asteraceae
ARTLUD	<i>Artemisia ludoviciana</i>	white sagebrush	Asteraceae
ASCSP	<i>Asclepias</i> sp.	milkweed	Asclepiadaceae
ASTRSP	<i>Astragalus</i> sp.	milkvetch	Fabaceae
ASTSP	<i>Aster</i> sp.	aster	Asteraceae
BASSP	<i>Bassia</i> sp.	burningbush	Chenopodiaceae
BIDCER	<i>Bidens cernua</i>	nodding beggartick	Asteraceae
BRODIA*	<i>Bromus diandrus</i>	ripgut brome	Poaceae
BROTEC*	<i>Bromus tectorum</i>	cheatgrass	Poaceae
CAMSP	<i>Camissonia</i> sp.	evening primrose	Onagraceae

CARSP	<i>Carex</i> sp.	sedge	Cyperaceae
CENREP*	<i>Centaurea repens</i>	Russian knapweed	Asteraceae
CHAFEN	<i>Chamaesyce fendleri</i>	Fendler spurge	Euphorbiaceae
CHEALB	<i>Chenopodium album</i>	lambsquarters	Asteraceae
CONCAN	<i>Conyza canadensis</i>	Canadian horseweed	Asteraceae
CORAME	<i>Corispermum americanum</i>	American bugseed	Chenopodiaceae
CRYFLA	<i>Cryptantha flava</i>	Brenda's yellow cryptantha	Boraginaceae
CYPERY	<i>Cyperus erythrorhizos</i>	red-root flatsedge	Cyperaceae
DATWRI	<i>Datura wrightii</i>	sacred thorn-apple	Solanaceae
DESPIN	<i>Descurainia pinnata</i>	western tansymustard	Brassicaceae
DISSPI	<i>Distichlis spicata</i>	saltgrass	Poaceae
ECHSP	<i>Echinocereus</i> sp.	hedgehog cactus	Cactaceae
ELYELY	<i>Elymus elymoides</i>	squirreltail	Poaceae
ELESP	<i>Eleocharis</i> sp.	spikerush	Cyperaceae
ENCFRU	<i>Encelia frutescens</i>	button brittlebush	Asteraceae
EPHVIR	<i>Ephedra viridis</i>	mormon tea	Ephedraceae
EQUSP.	<i>Equisetum</i> sp.	horsetail	Equisetaceae
ERAHYP	<i>Eragrostis hypnoides</i>	teal lovegrass	Poaceae
ERISP2	<i>Erigeron</i> sp.	fleabane	Asteraceae
ERISP	<i>Eriogonum</i> sp.	buckwheat	Polygonaceae
EUTOCC	<i>Euthamia occidentalis</i>	western goldentop	Asteraceae
GNASTR	<i>Gnaphalium stramineum</i>	cottonbatting plant	Asteraceae
GRASPI	<i>Grayia spinosa</i>	spiny hopsage	Chenopodiaceae
GRISQU	<i>Grindelia squarrosa</i>	curlycup gumweed	Asteraceae
HALGLO*	<i>Halogeton glomeratus</i>	saltlover	Chenopodiaceae
HELPEP	<i>Helianthus petiolaris</i>	prairie sunflower	Asteraceae
HETVIL	<i>Heterotheca villosa</i>	hairy false goldenaster	Asteraceae
IVAAXI	<i>Iva axillaris</i>	povertyweed	Asteraceae
LAPOCC	<i>Lappula occidentalis</i>	flatspine stickseed	Boraginaceae
LEPALY	<i>Lepidium alyssoides</i>	pepperwort	Brassicaceae
LEPLAT*	<i>Lepidium latifolium</i>	tall whitetop	Brassicaceae
LEPMON	<i>Lepidium montanum</i>	mountain pepperweed	Brassicaceae
MACCAN	<i>Machaeranthera canescens</i>	hoary tansyaster	Asteraceae
MAHFRE	<i>Mahonia fremontii</i>	Fremont's mahonia	Berberidaceae
MELSP	<i>Melilotus</i> sp.	sweetclover	Fabaceae
MIRLIN	<i>Mirabilis linearis</i>	narrowleaf umbrellawort	Nyctaginaceae
MUHSP	<i>Muhlenbergia</i> sp.		Poaceae
OPUERI	<i>Opuntia erinacea</i>	common pricklypear	Cactaceae
PANCAP	<i>Panicum capillare</i>	witchgrass	Poaceae
PANOBT	<i>Panicum obtusum</i>	vine mesquite	Poaceae
PENSP	<i>Penstemon</i> sp.	penstemon	Scrophulariaceae
PHRAUS	<i>Phragmites australis</i>	common reed	Poaceae
PHYCUN	<i>Phyla cuneifolia</i>	wedgeleaf	Verbenaceae
PLAMAJ*	<i>Plantago major</i>	common plantain	Plantaginaceae
PLAPAT	<i>Plantago patagonica</i>	woolly plantain	Plantaginaceae
POAFEN	<i>Poa fendleriana</i>	muttongrass	Poaceae

POTSP	<i>Potentilla</i> sp.	cinquefoil	Rosaceae
SALTRA*	<i>Salsola tragus</i>	Russian thistle	Chenopodiaceae
SCHSP	<i>Schizachyrium</i> sp.	bluestem	Poaceae
SESVR	<i>Sesuvium verrucosum</i>	sea purslane	Aizoaceae
SONOLE*	<i>Sonchus oleraceus</i>	common sowthistle	Asteraceae
SPHCOC	<i>Sphaeralcea coccinea</i>	scarlet globemallow	Malvaceae
SPHPAR	<i>Sphaeralcea parvifolia</i>	smallflower globemallow	Malvaceae
SPOAIR	<i>Sporobolus airoides</i>	alkali saccaton	Poaceae
SPOCON	<i>Sporobolus contractus</i>	spike dropseed	Poaceae
SPOCRY	<i>Sporobolus cryptandrus</i>	sand dropseed	Poaceae
SPOFLE	<i>Sporobolus flexuosus</i>	mesa dropseed	Poaceae
STAPIN	<i>Stanleya pinnata</i>	desert princesplume	Brassicaceae
STPAU	<i>Stephanomeria pauciflora</i>	wirelettuce	Asteraceae
STIHYM	<i>Stipa hymenoides</i>	Indian ricegrass	Poaceae
SUATOR	<i>Suaeda torryana</i>	Torrey seepweed	Chenopodiaceae
VERTHA*	<i>Verbascum thapsus</i>	mullein	Scrophulariaceae
XANSTR*	<i>Xanthium strumarium</i>	cocklebur	Asteraceae
YUCSP	<i>Yucca</i> sp.	yucca	Agavaceae

Table 3. Establishment events of patches of overstory species documented through historical aerial photo analysis. See Table 1 for species abbreviations.

<u>Species</u>	<u>Time period</u>	<u>River Section (number of patches)</u>
CELLAE	1984-1995	Cataract (1)
POPFRE	1976-1995	Green (1)
POPFRE	1995-2002	Green (6)
SALAMY	1995-2002	Colorado (2)
SALEXI	1984-1995	Green (2), Cataract (3)
SALEXI	1995-2002	Green (1), Cataract (2)
SALEXI	2002-2008	Green (1), Cataract (5)
SALGOO	1995-2002	Cataract (1)
SALGOO	2002-2008	Cataract (2)
SARVER	1976-1984	Cataract (3)
SARVER	1984-1995	Cataract (3)
SARVER	1995-2002	Cataract (2)
TAMSP	1984-1995	Cataract (1)
TAMSP	1995-2002	Cataract (1)
TAMSP	2002-2008	Cataract (4)
<i>Totals:</i>		
Cataract (28)		
Green (11)		
Colorado (2)		

Table 4. Seedling presence (%) at random seedling surveys by river section. The statistical difference among rivers was determined using Bonferroni multiple comparisons with a family-wise confidence level of 95%. Values with the same letters do not differ significantly, and the sample sizes are in parentheses.

River	<i>Tamarix</i>	<i>S. exigua</i>
Green (64)	60.9 a	85.9 a
Colorado (24)	62.5 a	87.5 a
Cataract (9)	66.7 a	88.9 a
Grand Canyon (144)	59.0 a	18.1 b

Table 5. Average measurements of soil characteristics by river. Statistical difference is based on Bonferroni-corrected 95% confidence intervals. Means with the same letter do not differ significantly. The sample sizes are not equal to those in table 4 because soil was not present at all sites. Units are: $\mu\text{g/g}$ (NH_4 , NO_3 , & total N), dSm^{-1} (EC), and % (NH_4/N & soil texture).

River	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	N	NH_4/N	pH	EC	Coarse	Sand	Fines
Green (59)	0.37ab	0.58a	0.95a	46.01a	9.08a	2.38a	0.08a	81.83a	18.09a
Colorado (22)	0.34ab	2.78a	3.12a	47.41a	8.64b	2.15a	0.23ab	70.82b	28.96b
Cataract (9)	0.72b	2.54a	3.26a	46.29a	8.78ab	1.50a	5.92b	76.09ab	7.99ab
Grand Canyon (136)	0.31a	1.34a	1.65a	38.74a	8.01c	4.77a	1.47ab	85.26a	14.07a

Table 6. Relative importance of each explanatory variable or sum of AIC weights (w_i) across models for *S. exigua* and *Tamarix* seedlings. The direction of effect is also given.

Variable	<i>Salix exigua</i>	w_i	<i>Tamarix</i>	w_i
pH	-	0.753	+	0.091
nitrate	+	0.562	+	0.499
ammonium	+	0.122	+	0.305
EC	+	0.156	+	0.360
Fines	+	0.145	+	0.089
NH_4/N	+	0.098	-	0.463

Table 7. Jaccard's coefficient of community representing the associations between overstory (columns) and understory (rows) species. Coefficients in bold font are ≥ 0.10 . See table 1 for species abbreviations. Asterices indicate non-native species.

	ACENEG	ATRSP	CELLAE	FORPUB	POPFRE	RHUTRI	SALEXI	SALGOO	SARVER	TAMSP*	
BASSP*	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.05	BASSP*
BROTEC*	0.04	0.02	0.07	0.07	0.11	0.02	0.07	0.04	0.05	0.15	BROTEC*
CYPERY	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.06	CYPERY
DISSPI	0.00	0.02	0.00	0.04	0.09	0.04	0.05	0.02	0.06	0.12	DISSPI
LEPSPP	0.08	0.04	0.02	0.09	0.05	0.04	0.08	0.06	0.00	0.07	LEPSPP
MACCAN	0.00	0.00	0.08	0.02	0.10	0.00	0.00	0.00	0.00	0.08	MACCAN
PHRAUS	0.05	0.00	0.00	0.05	0.00	0.05	0.06	0.05	0.04	0.01	PHRAUS
SALTRA*	0.00	0.05	0.07	0.05	0.05	0.03	0.05	0.03	0.02	0.07	SALTRA*
SPOSP	0.00	0.00	0.05	0.04	0.06	0.00	0.04	0.00	0.00	0.10	SPOSP
STAPIN	0.05	0.05	0.04	0.07	0.06	0.03	0.06	0.03	0.00	0.05	STAPIN
STIHYM	0.00	0.05	0.07	0.03	0.02	0.00	0.01	0.00	0.00	0.04	STIHYM
SUATOR	0.00	0.00	0.00	0.02	0.11	0.00	0.04	0.00	0.07	0.00	SUATOR
XANSTR*	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.06	XANSTR*

Figure 1. Map of study area and fourteen vegetation mapping sites.

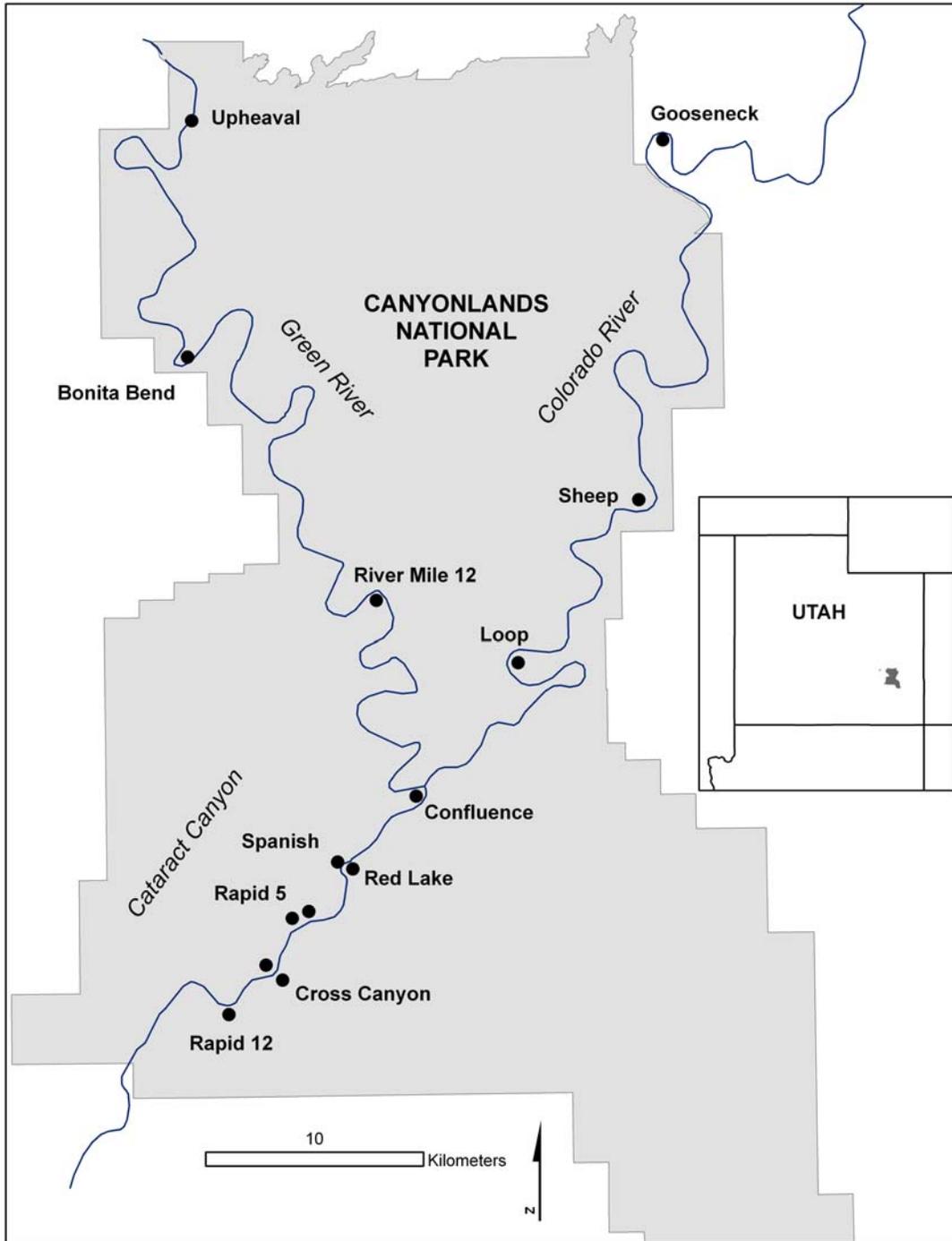


Figure 2. Mean daily flow of Colorado River near Cisco, UT (gaging station # 9810500). Arrows indicate years from which historical aerial photographs were analyzed. 1984 photos (hollow arrow) were only available for six sites.

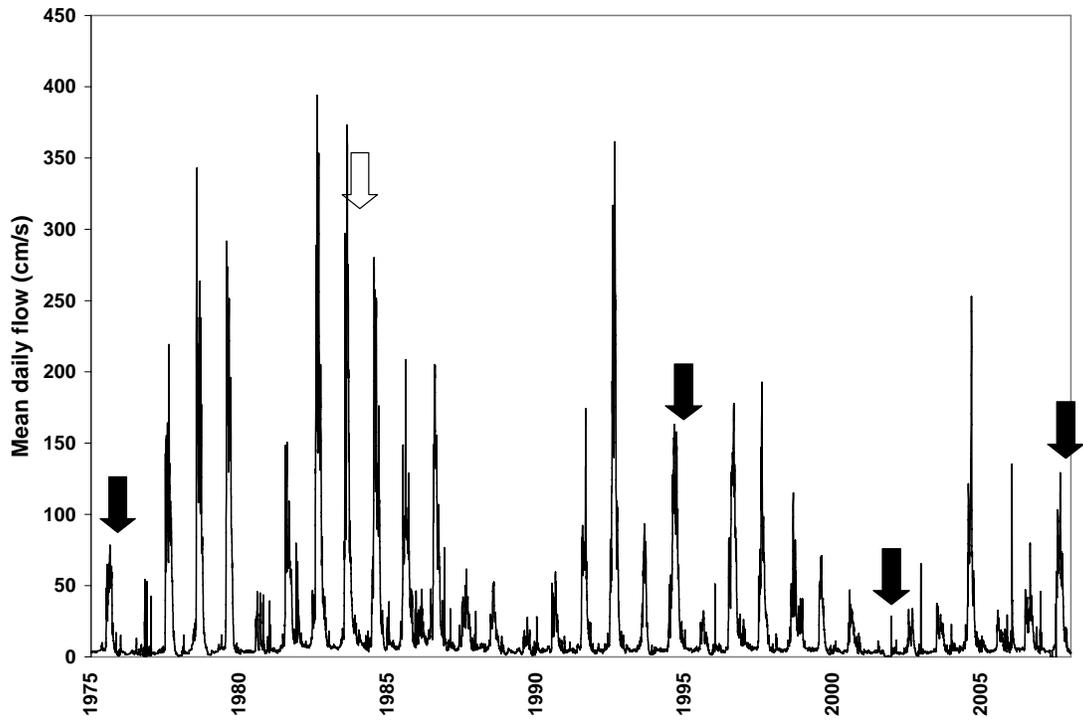


Figure 3. Mean daily flow of the Green River near Green River, UT (9315000). Arrows indicate years from which historical aerial photographs were analyzed. 1984 photos (hollow arrow) were only available for six sites.

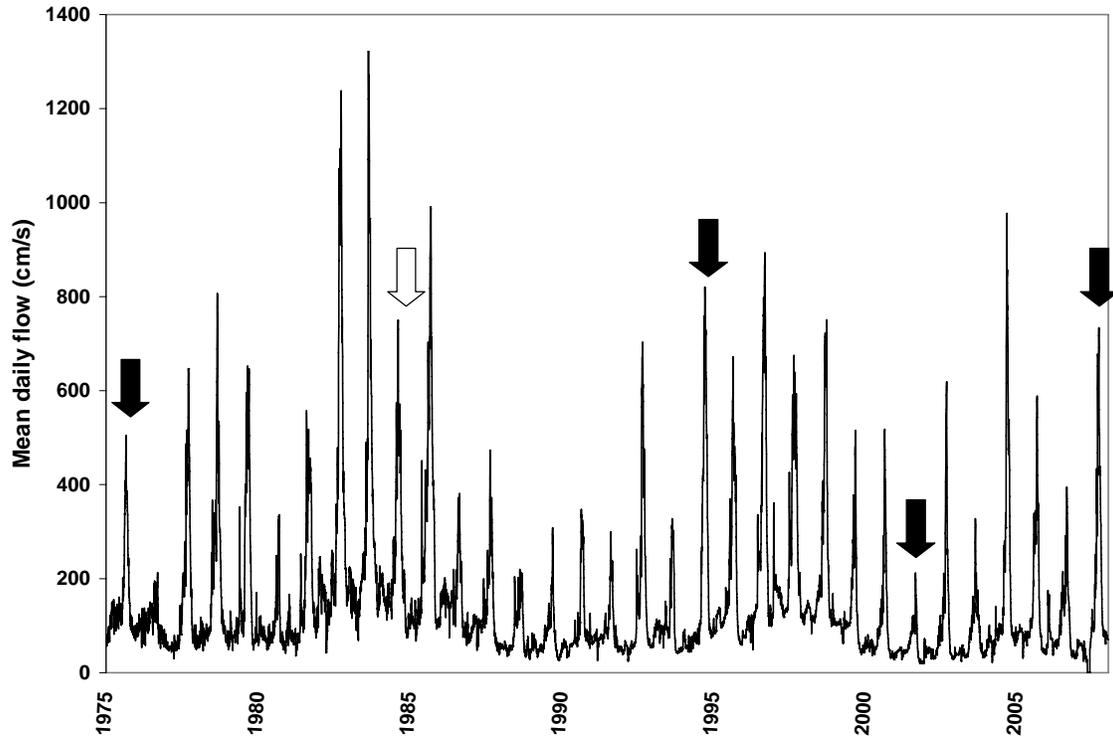


Figure 4. Vegetation composition of sampling sites along the (a) Colorado River (n = 3), (b) Green River (n = 3), and (c) Cataract Canyon (n = 8) in 2008.

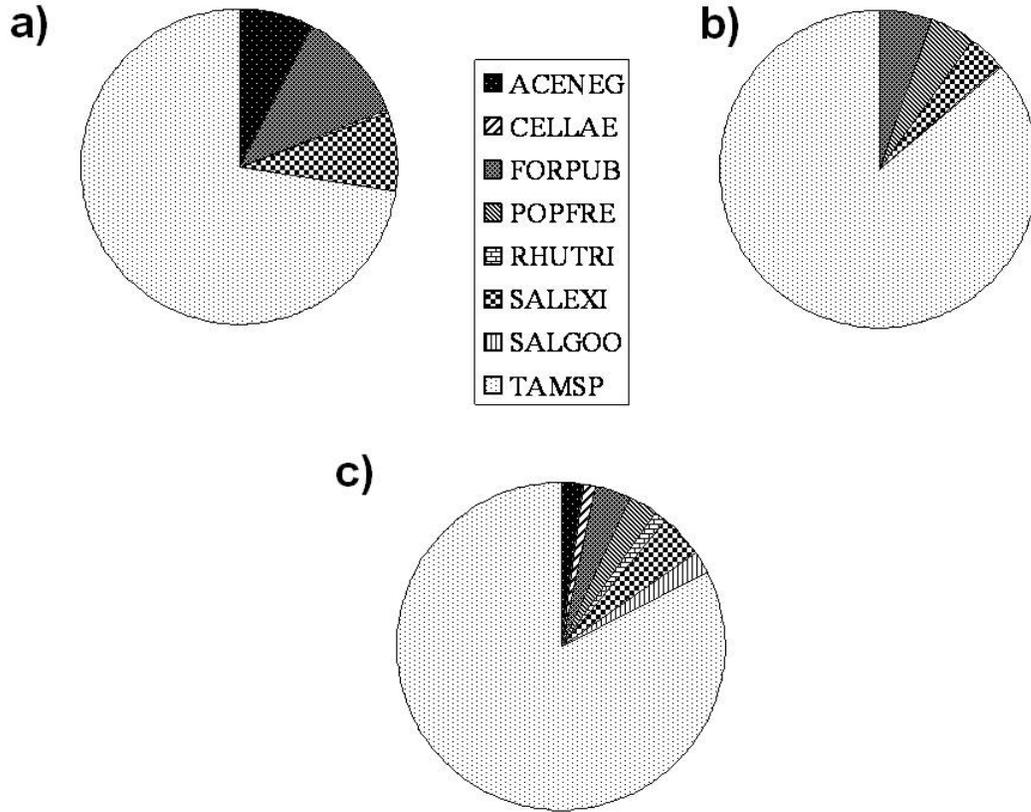


Figure 5. Total area of riparian vegetation sampled along three river sections and total for each of the four years sampled. Note different y-axis scales.

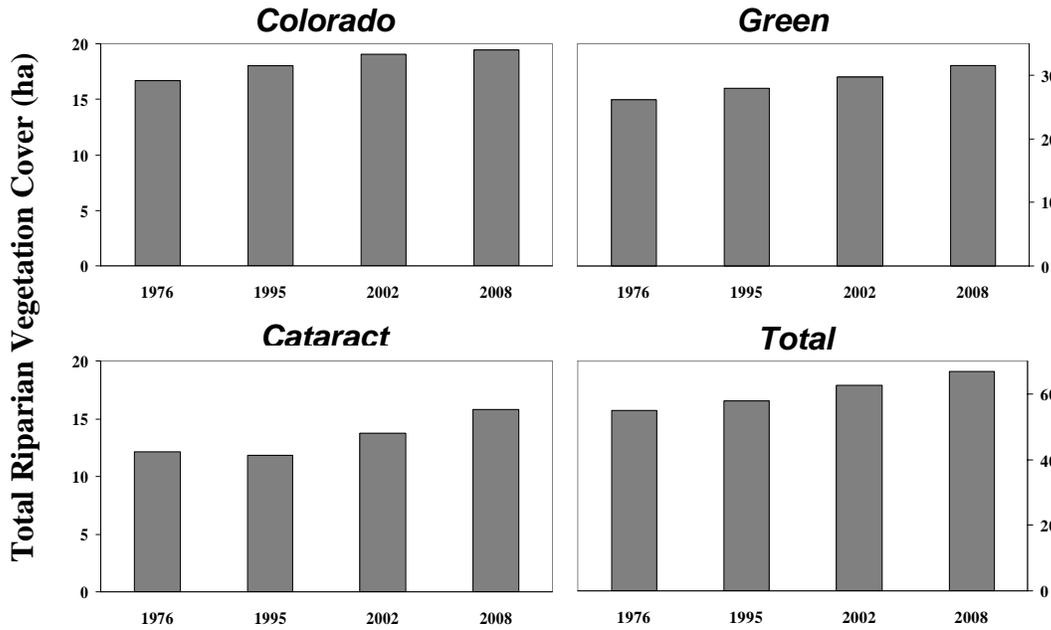


Figure 6. Relative vegetation cover of dominant overstory species at three sites along Colorado River. Bars indicate standard deviation.

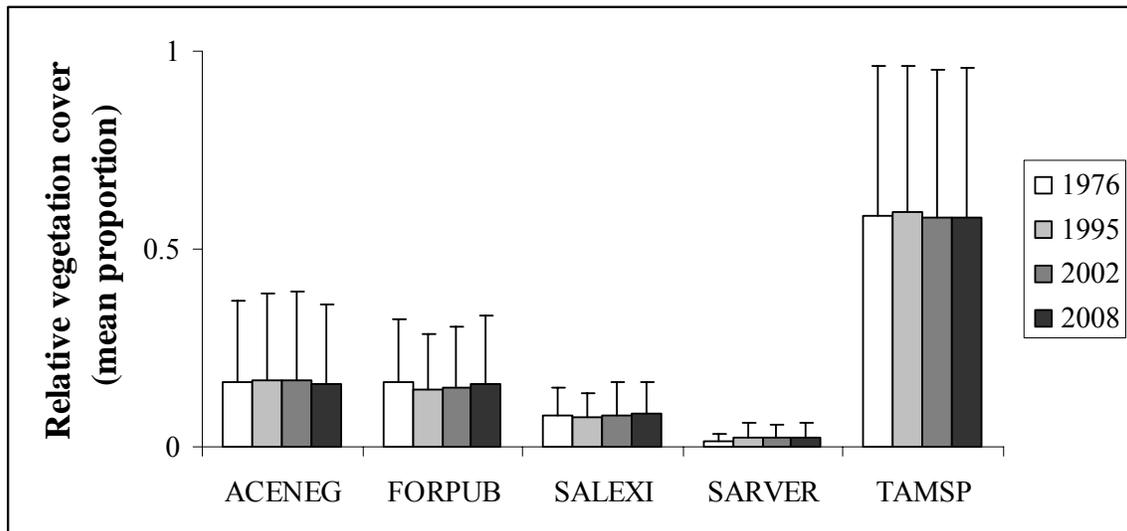


Figure 7. Relative vegetation cover of dominant overstory species at three sites along the Green River. Bars indicate standard deviation.

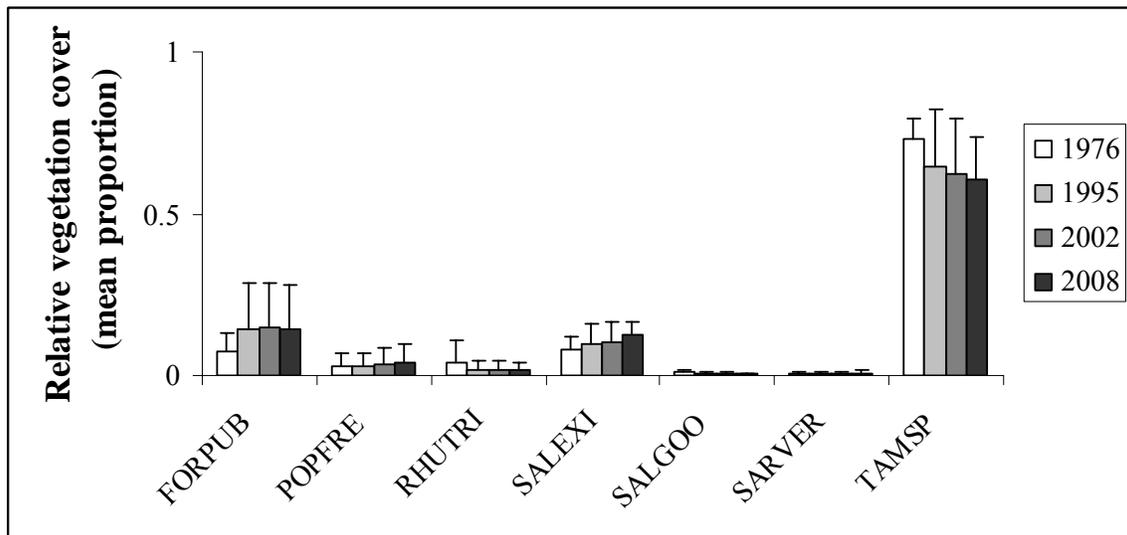


Figure 8. Relative vegetation cover of dominant overstory species at eight sites in Cataract Canyon. Bars indicate standard deviation.

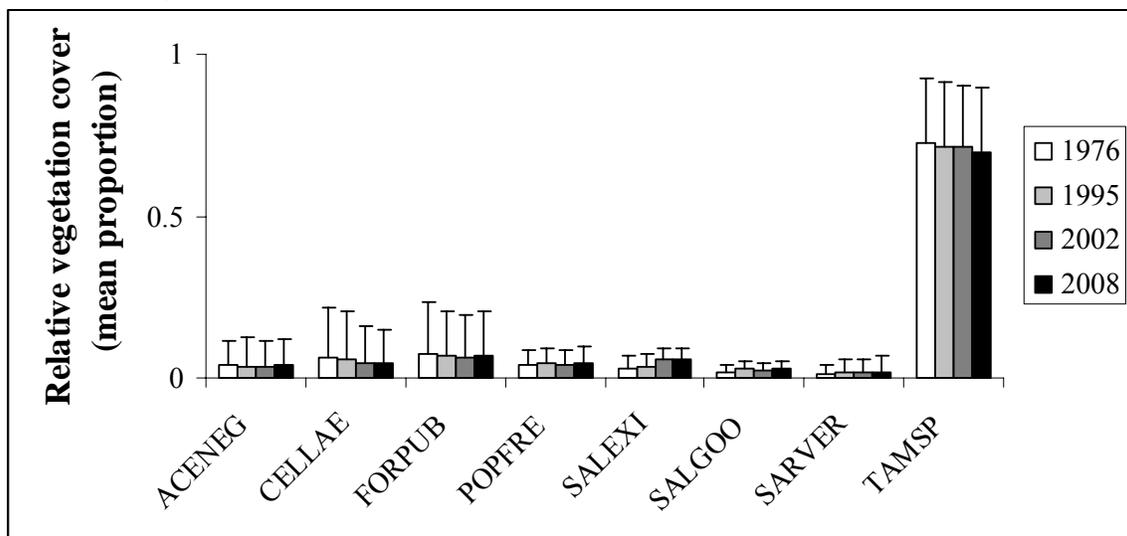


Figure 9. Average change in patch size of dominant riparian woody species (>75% cover) standardized by the patch size of latter time period during four time periods. Bars show standard error, and the number of patches is noted parenthetically.

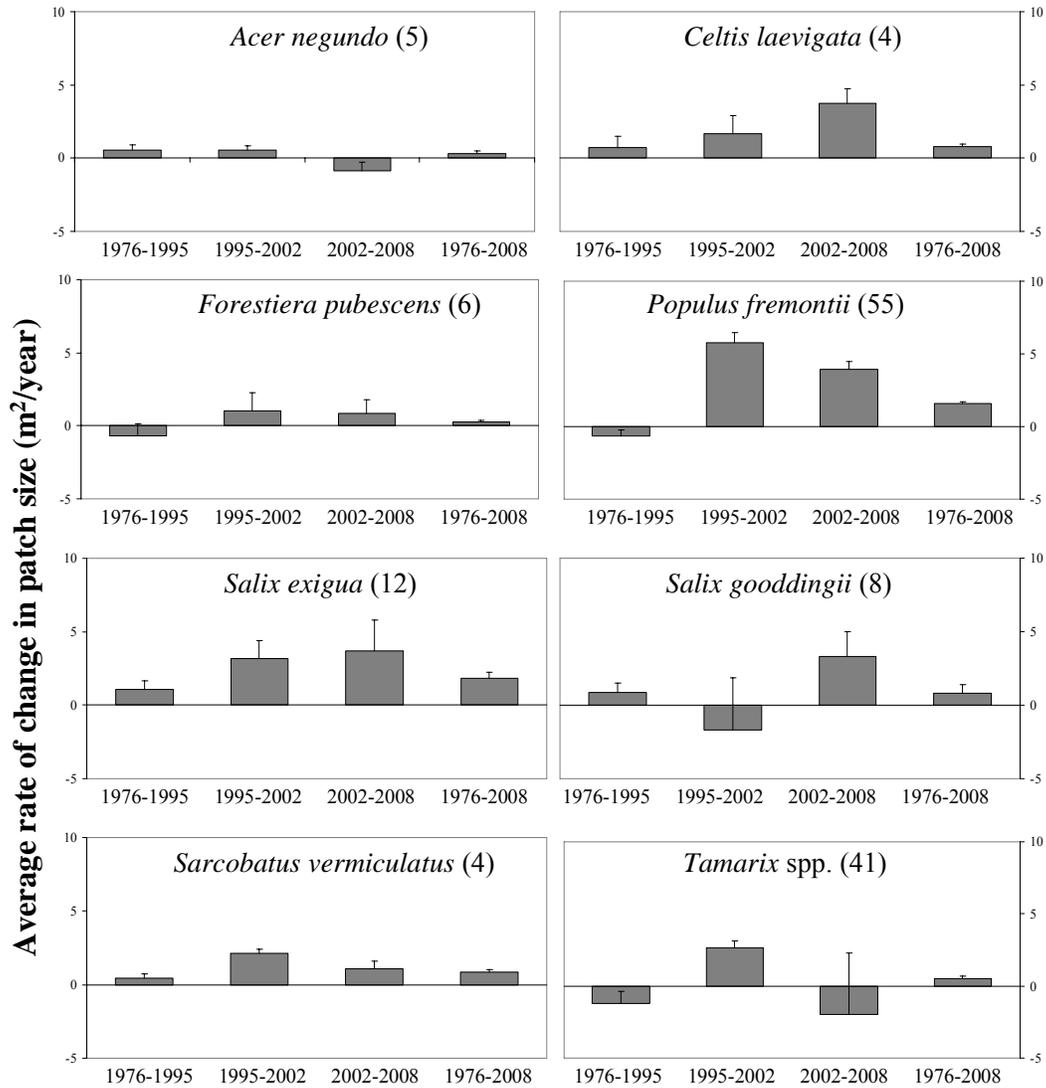


Figure 10. Average change in patch size of dominant riparian woody species (>75% cover) standardized by the patch size of latter time period during five time periods. Bars show standard error, and the number of patches is noted parenthetically.

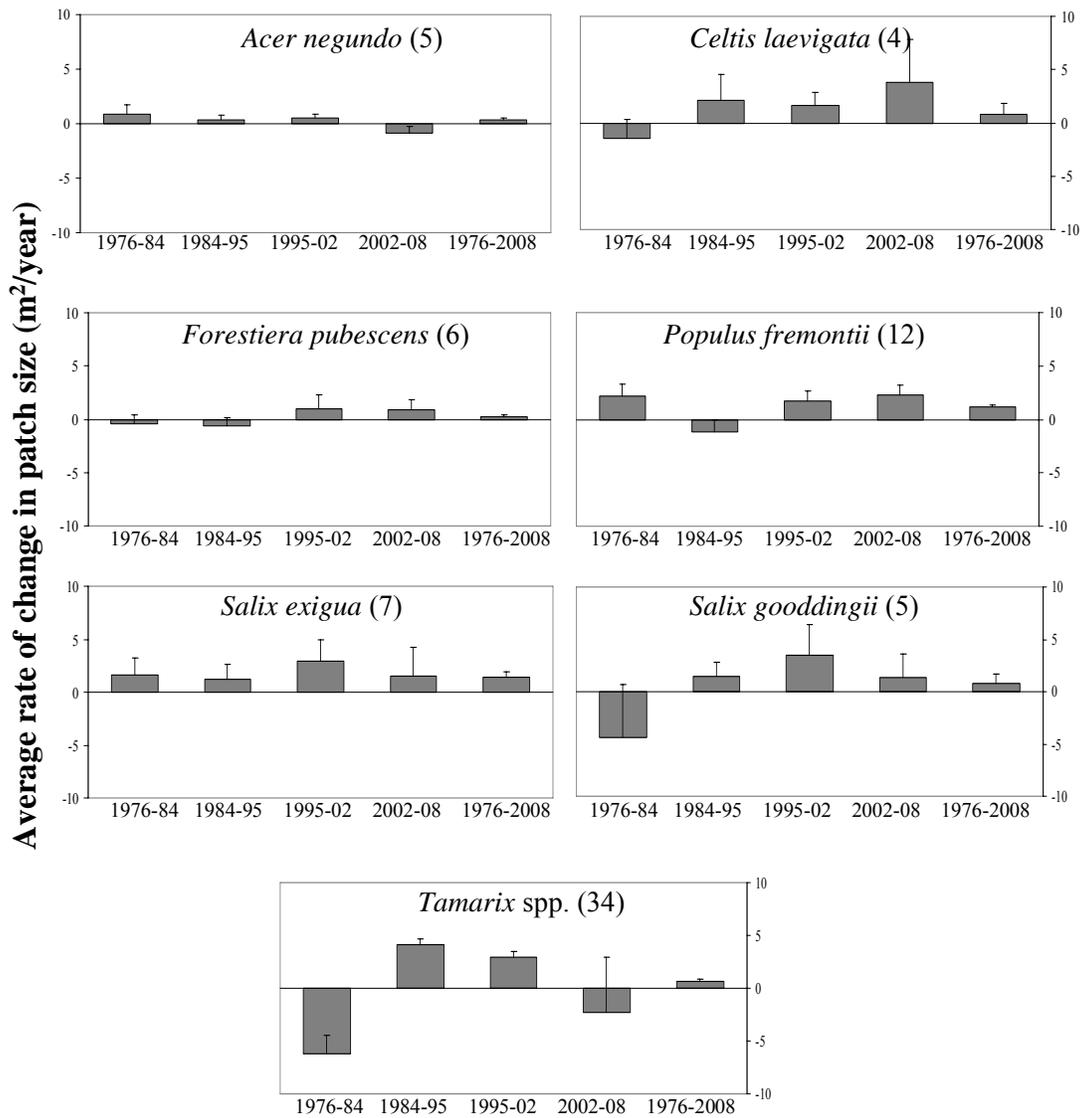


Figure 11. Average elevation above river level of patches containing riparian understory species. Error bars show standard error.

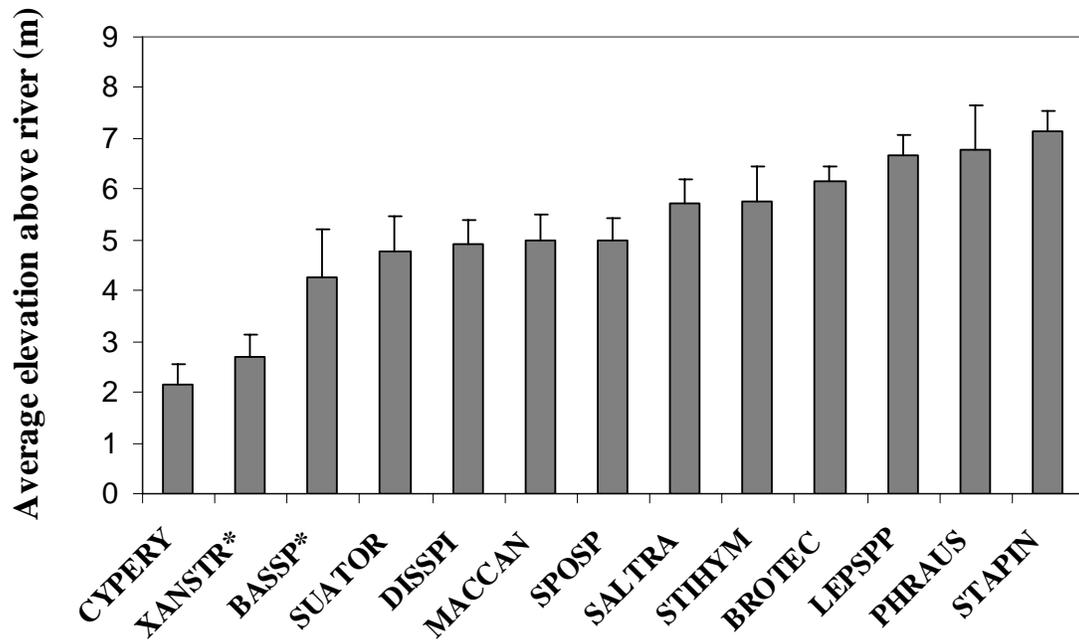


Figure 12. Average canopy cover of overstory species in patches containing understory species. Error bars show standard error.

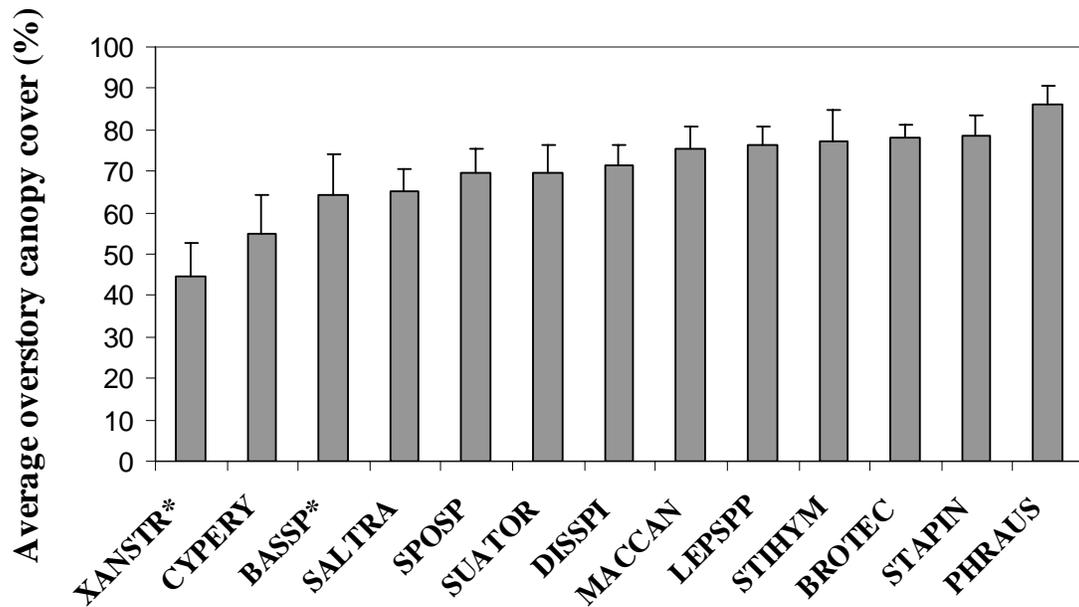


Figure 13. Average height of overstory canopy in patches containing understory species. Error bars show standard error.

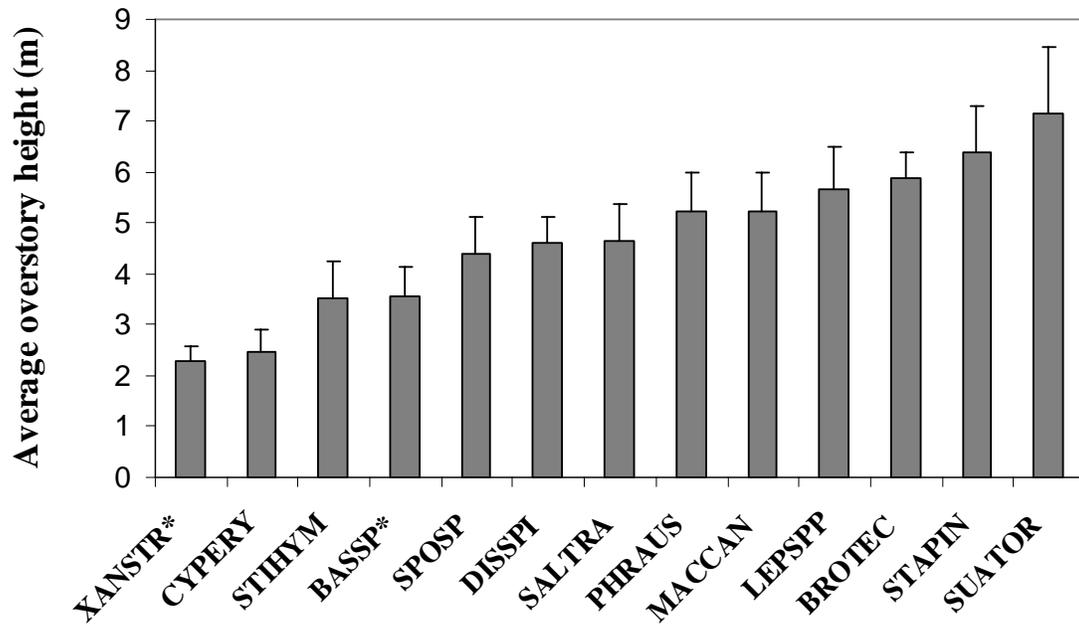


Figure 14. Total July and August precipitation recorded at the Moab, UT station # 425733 from 1975 to 2008. Arrows indicate years from which historical aerial photographs were analyzed.

