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GROWTH AND SURVIVORSHIP OF FREMONT COTTONWOOD, GOODDING WILLOW, AND SALT CEDAR SEEDLINGS AFTER LARGE FLOODS IN CENTRAL ARIZONA

J.C. Stromberg

ABSTRACT.—During winter 1993, Arizona experienced regional river flooding. Floodwaters at the Hassayampa River eroded floodplains and created a 50-m-wide scour zone available for colonization by pioneer plant species. The slow rate and long duration of the floodwater recession allowed establishment of spring-germinating native trees (mainly Fremont cottonwood [Populus fremontii] and Goodding willow [Salix gooddingii]) as well as summer-germinating species including the introduced salt cedar (Tamarix chinensis and related species). Goodding willow and Fremont cottonwood seedlings showed zonation in the floodplain, while salt cedar was equally abundant in zones with saturated and dry surface soils. Floodplain elevation (and soil moisture) influenced shoot growth rate to different degrees among the 3 species. For example, Goodding willow seedlings were significantly taller in areas with saturated soils than dry surface soils; Fremont cottonwoods were taller in the dry surface soil areas; and salt cedar were equally short in both soil moisture zones. Other factors that differentially influenced abundance or growth rates included competition with herbaceous species (Melilotus spp., an introduced plant, locally preempted salt cedar establishment) and herbivory (selective browsing by livestock at 1 river site reduced the natural height advantage of the native tree species). I draw on the results of this descriptive field study to suggest ways in which stream flows and floodplain land use can be managed to restore ecological conditions that favor native tree species over the introduced and widespread salt cedar.

Key words: riparian habitats, floods, Populus fremontii, Salix gooddingii, Tamarix chinensis.

Fremont cottonwood (Populus fremontii) and Goodding willow (Salix gooddingii) are pioneer species that establish episodically after winter/spring flood flows along rivers of the desert Southwest (Stromberg et al. 1991, Everitt 1995). Winter/spring floods scour competing vegetation, deposit and rework alluvial sediments, and provide supplemental moisture during the short period in spring during which the seeds disperse and germinate. Salt cedar (Tamarix chinensis and related species), an invasive riparian shrubby tree native to Eurasia, also is adapted to establish after flood disturbance but establishes more opportunistically than Fremont cottonwood and Goodding willow (Brock 1994). Salt cedar initiates seed dispersal later in the season but disperses its seeds over a longer period of time (Warren and Turner 1975). Thus, depending in part on timing and duration, floods may either preclude or enhance salt cedar establishment. For example, salt cedar seedlings were scarce after a small spring flood in the Hassayampa River in 1991 because the narrow band of germination space created by the rapidly receding floodwaters was colonized by Fremont cottonwood, Goodding willow, and herbaceous vegetation (Stromberg et al. 1993). Larger floods of longer duration, in contrast, have been observed to facilitate establishment of various species of Tamarix (Stevens and Waring 1985, Ohmart et al. 1988, Griffin et al. 1989).

During winter 1993, Arizona experienced regional river flooding. Although instantaneous peaks were on par with other recent large floods, the 1993 event ranked as one of the most severe in state history when collectively considering magnitude, duration, and volume (House 1995). The 1993 floods caused much geomorphic and vegetational change, including channel widening (Huckleberry 1994) and mass wasting of floodplains supporting velvet mesquite (Prosopis velutina) woodland and Fremont cottonwood–Goodding willow forest. The floods also created extensive habitat for riverine marshland and young stands of cottonwood and willow (Stromberg et al. 1997). I undertook this study with the objective of determining how abundance, distribution, growth, and survivorship of seedlings and vegetative...
sprouts of Fremont cottonwood, Goodding willow, salt cedar, and various shrubs were influenced by the 1993 floods, and by hydrologic events in subsequent years.

**STUDY SITES**

Study sites are located on perennial reaches of 3 central Arizona Sonoran rivers. One site is in the Arizona Nature Conservancy's Hassayampa River Preserve in northwest Maricopa County (elevation ca 600 m). The Hassayampa River has a mean annual flow rate of 0.5 m$^3$s$^{-1}$ at the Morristown gage (USGS #9516500), located about 4 km downstream of the preserve. Surface sediments are predominantly sand. Surface water has an electrical conductivity of 600-700 μS/cm. The area was grazed by cattle prior to 1987, but the main land use at the preserve is now ecotourism. The Santa Maria River study site is in the Alamo Lake Wildlife Management Area (elevation 365 m), in Mohave and La paz counties, and is grazed by feral burro and trespass cattle. Mean annual flow rate of the Santa Maria is 2 m$^3$s$^{-1}$ at the Baghdad gage (USGS #9424900), located about 5 km upstream of the study reach. The Date Creek site is on Arizona State land, leased by Date Creek Ranch (elevation 880 m). Date Creek is a tributary to the Santa Maria River and is not gaged. The Date Creek floodplain is grazed by cattle from November to March.

Floodplains of all 3 rivers are vegetated primarily by Fremont cottonwood–Goodding willow forests, velvet mesquite woodlands, burro brush (*Hymenoclea monogyna*) scrublands, and seep willow (*Baccharis salicifolia*) stands (Brown 1982). Other woody species include Arizona ash (*Fraxinus velutina*), Bonpland willow (*Salix bonplandiana*), coyote willow (*Salix exigua*), arrow weed (*Tessaria sericea*), and screwbean mesquite (*Prosopis pubescens*). Salt cedar had lower density than Fremont cottonwood or willows at study sites at all 3 rivers (Table 1), based on sampling of saplings and trees (stems >2 cm at breast height) in 1994 with the point-quarter method (20 points per river).

**METHODS**

At the Hassayampa River, data were collected at a total of 100 permanent plots distributed along 8 transects established at the preserve in 1987. Plots were located at known distances along the transect line, allowing for reestablishment of plot markers (rebar) that were removed or buried during floods. Floodplain topography and changes in plot surface elevation due to sediment deposition and scour were determined based on repeat cross-sectional surveys of the Hassayampa River transects (Stromberg et al. 1997). Plots (1 x 1 m) were sampled for density and height of woody seedlings and vegetative stem sprouts 3-5 times per year during 1993, 1994, and 1995. Shoot height was measured for the tallest individual per species per plot. Plants were assumed dead if absent from plots, although live root or stem fragments may have been dispersed from plots in floodwaters. The nonparametric Kruskal-Wallis test was used to test for significant differences in survivorship of the 1995 flood between 1993 seedling cohorts of Fremont cottonwood, Goodding willow, and salt cedar. Spearman rank correlation analysis was used to determine whether seedling survivorship of the 1995 flood varied with distance from the 1993 channel edge. SPSS for Windows was used for all statistical analyses.

At all 3 rivers, 50 randomly located 1 x 1-m plots were sampled in June and October of 1994 within 1 or 2 soil moisture zones in the scoured flood channel. Fifty plots were in a zone with saturated surface soils or shallow standing water (<3 cm), and 50 were in a zone with slightly higher surface elevation (10-30 cm higher) and dry or damp surface soils (as of June 1994). At Date Creek the saturated soil zone was not extensive, and plots were sampled only in the dry surface zone. Woody seedlings in the plots were sampled for density, and for height and browse status (browsed or unbrowsed) of the tallest individual per species. Plants were classified as browsed if any of the shoots had been eaten. If there were <20 individuals of Fremont cottonwood, Goodding

<table>
<thead>
<tr>
<th>Study Sites</th>
<th>Fremont cottonwood</th>
<th>Goodding and Bonpland willows</th>
<th>Salt cedar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hassayampa River</td>
<td>287</td>
<td>412</td>
<td>45</td>
</tr>
<tr>
<td>Santa Maria River</td>
<td>312</td>
<td>416</td>
<td>195</td>
</tr>
<tr>
<td>Date Creek</td>
<td>45</td>
<td>60</td>
<td>5</td>
</tr>
</tbody>
</table>
willow, or salt cedar in the 50 plots, stem height and browse status were measured in additional random plots to increase sample size to 20 individuals per species per zone. Herbaceous cover, by species, was visually estimated in the plots using gridded plot frames to reduce sampling error.

One-way analysis of variance (ANOVA) with post-hoc Sheffe's multiple comparison test was used to detect statistical difference in stem density ($n = 50$ plots) and stem height ($n = 20$ individuals per species) between Fremont cottonwood, Goodding willow, and salt cedar within zones of each river. Independent sample Student's $t$ tests were used to compare density ($n = 50$ plots) and stem height ($n = 20$) of each species between the saturated and dry surface zones of the Hassayampa and Santa Maria rivers. Additionally, plots within the dry surface zone at the Hassayampa River were subsequently divided into those with >50% and <50% cover of sweet clover (*Melilotus albus* and *M. officinalis*), and densities of salt cedar and Fremont cottonwood were compared between the 2 groups with Student's $t$ tests.

**RESULTS**

**Surface Flow**

The 1993 flood in the Hassayampa River had a 25-yr recurrence interval, with instantaneous flow rates peaking at 745 m$^3$s$^{-1}$ on 8 January 1993. This was followed by flood peaks of 218 m$^3$s$^{-1}$ on 17 January, 328 m$^3$s$^{-1}$ on 9 February, and 439 m$^3$s$^{-1}$ on 20 February. Surface flow was above average during spring and summer of 1993 and was present through August at the Morristown gage, located in a frequently dry reach of the Hassayampa River (Fig. 1). Floodwaters in 1993 had an estimated depth of 3.0 m on low floodplain terraces and a velocity of 2.1 m s$^{-1}$. Floodwaters enlarged the channel from about 3 to 50 m wide and caused a net lowering of the floodplain surface. Throughout 1994, instantaneous flow rates never exceeded 2 m$^3$s$^{-1}$. During 1995, instantaneous flow rates peaked at 566 m$^3$s$^{-1}$ (15- to 20-yr recurrence interval) in February. Flows remained high in spring and summer of 1995 but diminished more rapidly than in 1993. Surface flow was present at the Morristown gage through June 1995. The 1995 floods deposited sediment on large portions of the floodplain, raising the elevation of the scour zone relative to 1993 (Stromberg et al. 1997). The Santa Maria also had large flood peaks. Instantaneous discharges in the Santa Maria peaked in 1993 at 347 m$^3$s$^{-1}$ on 8 January, 440 m$^3$s$^{-1}$ on 9 February, and 356 m$^3$s$^{-1}$ on 20 February.

**1993 Seedling Cohort**

**TEMPORAL AND SPATIAL DISTRIBUTION.**—As the Hassayampa River floodwaters receded in 1993, woody plants germinated in exposed moist soils in the following sequence: Fremont cottonwood (March–April), Goodding willow (April–May), salt cedar (May–September), arrow weed (July–September), and seep willow (July–September; Fig. 2). Trace amounts (<0.01 stem/m$^2$) of Bonpland willow were recorded from Date Creek (data not shown), but this species was not present at the Hassayampa River site.

Woody seedlings showed zonation in the floodplains of the Hassayampa and Santa Maria rivers (Table 2). Fremont cottonwood was significantly more abundant in dry surface zones, while Goodding willow, coyote willow, and arrow weed were significantly more abundant in zones with saturated soils. Salt cedar and seep willow were equally abundant in both zones. Within the dry surface zone at the Hassayampa River, however, salt cedar seedlings varied significantly ($t$ test, $P < 0.05$) in density depending on cover of yellow and white sweet clover (Fig. 3). Salt cedar seedlings were nearly absent in plots with high sweet clover cover but averaged 15 stems/m$^2$ in plots with little...
Fig. 2. Density of woody seedlings established after floods in 1993 and 1995 in the Hassayampa River (POFR = *Populus fremontii*, SAGO = *Salix gooddingii*, TACH = *Tamarix chinensis*, BASA = *Baccharis salicifolia*, TESE = *Tessaria sericea*).

At the end of the 1993 growing season (November), Fremont cottonwood seedlings had a mean density of 20 stems/m² in the Hassayampa River flood channel as a whole, followed by salt cedar (13 stems) and Goodding willow (9 stems). Values had declined to about 4 stems/m² for each species by October 1994. The 1995 floods caused high mortality of these remaining 1993 seedling cohorts. In Hassayampa River study plots, Fremont cottonwood and Goodding willow seedlings had 96% mortality, and salt cedar had 100% mortality. Between-species differences in survivorship were not statistically significant at $P < 0.05$. However, there was a significant correlation ($r = 0.50; P < 0.05; n = 28$) between woody seedling survivorship and distance of the plot from the edge of the channel as of 1993. Fremont cottonwoods and Goodding willows that did survive were mainly in narrow bands along the edge of the scour zone, with some surviving despite deposition of up to 1 m of sediment.

GROWTH RATES AND BROWSE RATES.—On average in the Hassayampa River floodplain, seedlings of native tree species (Goodding willow and Fremont cottonwood) were taller than salt cedar and native shrub species (seep willow and arrow weed; Fig. 5). Among tree species, Goodding willows were significantly taller than Fremont cottonwood and salt cedar during their 1st and 2nd growing seasons in the saturated soil zones at the Hassayampa and Santa Maria rivers (Fig. 6). In dry surface zones at river sites, the 3 species did not differ significantly in height after 1 growing season. After 2 growing seasons native tree species were significantly taller than salt cedar in the dry surface zone at the Hassayampa and Santa Maria rivers but not at Date Creek. Date Creek was the only study site with high rates of browse by livestock, with 89% of the Fremont cottonwood seedlings and 5% of the salt cedar seedlings classified as browsed as of June 1994. In most cases browsing resulted in loss of the terminal shoot. Browse rates were <5% per species at the other 2 rivers.

Fremont cottonwoods were significantly taller in the dry surface zone than in the saturated soil zones at both the Hassayampa and Santa Maria rivers, after 1 and 2 growing seasons (Table 3). In contrast, Goodding willows tended to be taller in the saturated soil zone, but differences between zones were significant only at the Hassayampa River during the 1st growing
Table 2. Stem density (no./m²) of 1993 seedling cohorts of *Populus fremontii* (POFR), *Salix gooddingii* (SAGO), *Tamarix chinensis* (TACH), *Baccharis salicifolia* (BASA), *Tessaria sericea* (TESE), and *Salix exigua* (SAEX) at the Hassayampa River Preserve (HR), Santa Maria River (SM), and Date Creek (DC), by moisture zone. Values shown are means ± standard errors. *t* indicates values less than 0.1.

<table>
<thead>
<tr>
<th></th>
<th>POFR</th>
<th>SAGO</th>
<th>TACH</th>
<th>BASA</th>
<th>TESE</th>
<th>SAEX</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>June 1994</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Dry surface: HR</td>
<td>38.3±5.9*</td>
<td>3.2±0.6</td>
<td>11.4±4.4</td>
<td>1.2±0.1</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
</tr>
<tr>
<td>Saturated soils: HR</td>
<td>1.2±0.3</td>
<td>38.1±5.7*</td>
<td>10.8±7.5</td>
<td>0.9±0.4</td>
<td>0.3±0.1*</td>
<td>0.0±0.0</td>
</tr>
<tr>
<td>Dry surface: SM</td>
<td>5.9±0.6*</td>
<td>0.3±0.2</td>
<td>34.3±5.9</td>
<td>1.3±0.4</td>
<td>0.1±0.1</td>
<td>0.0±0.0</td>
</tr>
<tr>
<td>Saturated soils: SM</td>
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<td>3.7±0.5*</td>
<td>27.6±4.7</td>
<td>1.3±0.7</td>
<td>5.2±0.7*</td>
<td>0.3±0.0*</td>
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<tr>
<td>Dry surface: DC</td>
<td>2.3±0.6</td>
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<td>0.9±0.3</td>
<td>0.6±0.2</td>
<td>0.0±0.0</td>
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<td><strong>October 1994</strong></td>
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<td></td>
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<tr>
<td>POFR</td>
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<td>0.4±0.2</td>
<td>7.8±1.7</td>
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<td>0.0±0.0</td>
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</tr>
<tr>
<td>SAGO</td>
<td>1.1±0.4</td>
<td>18.5±5.7*</td>
<td>9.6±2.6</td>
<td>0.3±0.1</td>
<td>0.3±0.1*</td>
<td>0.0±0.0</td>
</tr>
<tr>
<td>TACH</td>
<td>2.5±0.7*</td>
<td>0.0±0.0</td>
<td>5.1±1.4</td>
<td>0.3±0.1</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
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<tr>
<td>BASA</td>
<td>0.1±0.1</td>
<td>2.6±1.2*</td>
<td>7.4±2.4</td>
<td>0.1±0.1</td>
<td>1.9±0.6*</td>
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<tr>
<td>TESE</td>
<td>1.0±0.4</td>
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<td>0.8±0.3</td>
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<td>0.0±0.0</td>
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</tr>
</tbody>
</table>

*Significant difference between moisture zones at P < 0.05

Table 3. Stem height for 1993 seedling cohorts of *Populus fremontii* (POFR), *Salix gooddingii* (SAGO), and *Tamarix chinensis* (TACH) at the Hassayampa River Preserve (HR), Santa Maria River (SM), and Date Creek (DC), by moisture zone, after 1 and 2 growing seasons. Values shown are means ± standard errors.

<table>
<thead>
<tr>
<th></th>
<th>POFR</th>
<th>SAGO</th>
<th>TACH</th>
<th>POFR</th>
<th>SAGO</th>
<th>TACH</th>
</tr>
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<tbody>
<tr>
<td><strong>One growing season</strong></td>
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<td></td>
<td></td>
<td></td>
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<td>77±8</td>
<td>52±5</td>
<td>128±8*</td>
<td>125±11</td>
<td>53±7</td>
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<tr>
<td>Saturated soils: HR</td>
<td>45±6</td>
<td>103±9*</td>
<td>53±7</td>
<td>71±6</td>
<td>149±11</td>
<td>45±5</td>
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<tr>
<td>Dry surface: SM</td>
<td>60±6*</td>
<td>60±8</td>
<td>40±6</td>
<td>141±8*</td>
<td>—</td>
<td>74±6</td>
</tr>
<tr>
<td>Saturated soils: SM</td>
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<td>80±8</td>
<td>41±5</td>
<td>67±6</td>
<td>116±12</td>
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<tr>
<td>Dry surface: DC</td>
<td>46±6</td>
<td>66±9</td>
<td>47±6</td>
<td>55±5</td>
<td>—</td>
<td>45±4</td>
</tr>
</tbody>
</table>

*Measured in June 1994

*Two growing seasons

*Significant difference between moisture zones at P < 0.01.
Seedlings of all 3 tree species again germinated in 1995 in the moist, scoured zone exposed by the slowly receding floodwaters. In the Hassayampa River floodplain, densities of the 1995 seedling cohorts ranged among the 3 species from 1 to 4 stems/m² as of October 1995, compared to 9–20 stems/m² for the 1993 cohorts as of November 1993. Dry surface soils were relatively more abundant and saturated soils less abundant in 1995 than 1993, partly due to floodplain aggradation in 1995. Fremont cottonwood seedlings were the most abundant of the 3 tree species in 1995 and outnumbered salt cedar by a ratio of about 2:1 as of October 1995. Seedlings of all 3 species tended to have shorter stems in 1995 than in 1993, but the difference between years was significant at \( P < 0.05 \) only for Goodding willow (Fig. 7).

Densities of vegetative sprouts were greater in 1995 than during 1993. There were 0.25, 0.36, and 0.02 stems/m² for Fremont cottonwood, Goodding willow, and salt cedar, respectively, as of October 1995, compared to <0.01 stems per species in November 1993. Many of the 1995 sprouts originated from flood-prostrated 1993 seedlings. In 1995 and 1993, seedlings were an order of magnitude more abundant than vegetative sprouts.

**Discussion and Management Implications**

Salt cedar was subdominant to Fremont cottonwood and Goodding willow in mature forest stands at the 3 rivers included in this study. To maintain or relegate salt cedar to a subdominant role, stream flows and floodplain lands need to be managed to produce ecological conditions that favor native species. This study identified several factors that influence establishment rates of salt cedar vs. native tree species.

**Flood Timing, Magnitude, Duration, and Stage Decline Rate.**—The large magnitude and long duration of the 1993 and 1995 winter floods created extensive fluvial surfaces available for colonization by woody pioneer plant species that do not tolerate competitive herbaceous cover. The long, slow decline in the river stage (flow rates did not decline to base levels until several months after the flood peaks) allowed germination of woody species with a variety of temporal regeneration niches. Extensive scour prevented herbaceous species from rapidly colonizing the moist sediments that were exposed throughout the summer, and thus germination sites were available for spring-germinating native trees (Fremont cottonwood and Goodding willow) as well as for salt cedar, a species with biseasonal seed dispersal peaks in June–July and August–September (Horton 1957, 1977, Warren and Turner 1975).

Stream flows on regulated rivers are being naturalized in several ways to facilitate establishment of Fremont cottonwood and other native species (Stanford et al. 1996, Poff et al. 1997). The same could be done to reduce establishment of salt cedar. Scouring flows should be released during early spring in potential recruitment years for cottonwoods and willows. The flood flows need to be of sufficiently high magnitude and duration to rework sediments and create bare surfaces lying within about 1 m of the “base-flow” alluvial groundwater table (Stromberg et al. 1991, 1993). Flows should peak prior to Fremont cottonwood and Goodding willow spring seed dispersal periods (from about February to April, depending on elevation). River stage should decline during the short (month long) periods of cottonwood and
Fig. 4. Stem density of 1993 cohorts of *Populus fremontii* (POFR), *Salix gooddingii* (SAGO), and *Tamarix chinensis* (TACH), in dry surface and saturated soil zones, after 1 and 2 growing seasons (HR = Hassayampa River, SM = Santa Maria River, DC = Date Creek). Values shown are means and standard error bars. Asterisk indicates that a species had significantly different density from the other species at $P < 0.05$.

Fig. 5. Shoot heights of woody seedlings established after the 1993 flood (POFR = *Populus fremontii*, SAGO = *Salix gooddingii*, TACH = *Tamarix chinensis*, BASA = *Baccharis salicifolia*, TESE = *Tessaria sericea*).
willow seed viability to expose moist germination sites (Mahoney and Rood 1993, Braatne et al. 1997). The rate of stage decline (and of alluvial groundwater decline) during early seedling growth should not exceed rates of root growth of Fremont cottonwood and Goodding willow seedlings. These rates are about 1–3 cm per day and vary with soil texture (Mahoney and Rood 1992, Segelquist et al. 1993). To reduce salt cedar establishment, river stage should stabilize prior to the onset of salt cedar germination in late spring. This also could reduce germination rates for summer-germinating native pioneer species such as seep willow; however, if initial flood scour is not too great, this species will rapidly regenerate asexually (Stromberg et al. 1991).

Floods that occur after seed germination also may influence relative abundance of salt cedar vs. cottonwoods and willows. In this study the 1993 seedling cohorts of Fremont cottonwood, Goodding willow, and salt cedar all had high mortality from the 1995 flood, and survivorship did not differ significantly between the 3 species. However, some studies suggest that salt cedar may be less tolerant of the scouring effects.
of floods, but more tolerant of prolonged inundation, than cottonwood and willow trees (Warren and Turner 1975, Irvine and West 1979, Everitt 1980, Stevens and Waring 1985). Salt cedar seedlings may have low survivorship of floods because of their distribution in the floodplain. Because most salt cedar seeds germinate later than Fremont cottonwood and Goodding willow seeds, salt cedar seedlings sometimes are more abundant on sites close to the channel where risks of mortality from subsequent floods are high (Stromberg et al. 1991). Also, there may be physiological differences between species in tolerance for flood scour or burial by sediments. For example, low rates of shoot growth may increase the probability of complete burial of salt cedar seedlings. Existence of differential survivorship thresholds for factors such as shear stress and sediment deposition should be experimentally tested. If there are differences, release of occasional large, scouring floods in alluvial, perennial rivers in the Southwest may be a management strategy to increase the mortality of salt cedar seedlings and saplings relative to that of native pioneer tree species.

**SOIL MOISTURE.**—Differences in tree seedling shoot height between soil moisture zones in this study were most likely a result of differential responses to soil moisture and soil aeration. Goodding willow shoot height was greatest in conditions of saturated soils or standing water, whereas Fremont cottonwood shoot height was greatest in areas with dry surface soils but shallow water tables. Salt cedar were equally short in both zones. Comparison between years suggests that salt cedar is as tall as the native tree species under conditions of reduced water availability. Yearlings of all 3 tree species were somewhat shorter in 1995 than in 1993 (most likely due to lower river stage and deeper water tables); however, the difference between years was greater for native trees. Other studies demonstrate that salt cedar is more drought tolerant than native cottonwoods and willows and thus may have a competitive advantage on drier floodplains with deeper groundwater levels (Stevens 1987, Busch and Smith 1995). There is a need for additional controlled studies of seedling growth (Siscoe 1993, Shafroth et al. 1995) to quantify soil moisture ranges over which native species have a competitive edge. Once such ranges are described, activities that reduce floodplain water availability (such as surface water diversion and groundwater pumping) could be managed to produce soil moisture levels and groundwater depths that favor growth and survivorship of native species during establishment periods.

**GRAZING.**—Although this study was not explicitly designed to determine effects of livestock on riparian tree seedlings, there were differences in cattle browsing between sites which resulted in significant differences in seedling heights. At the 2 (legally) ungrazed river sites, Fremont cottonwood had a large height advantage over salt cedar in certain areas of the floodplain (i.e., dry surface soil zone). At Date Creek, which is grazed/browsed by cattle from November to March, selective browsing on Fremont cottonwood seedlings caused them to lose their height advantage over salt cedar. Between-species differences in seedling shoot height ultimately may determine the composition of the stand dominant, given that shorter plants may have greater mortality due to light limitation. All 3 species, including salt cedar, appear to be shade intolerant. Additionally, reduction in shoot height may reduce a seedling’s ability to survive deposition of sediment during flood events. To favor native tree species on cattle-grazed rivers, recruitment zones should be protected year-round from livestock.
during at least 2 growing seasons to allow seedlings to grow above browse height.

**HERBACEOUS PLANT COMPETITION.**—In localized areas of the Hassayampa River floodplain, the exotic herbaceous species yellow and white sweet clover preempted establishment of salt cedar by germinating in spring and rapidly covering the ground surface prior to salt cedar germination. Fremont cottonwood seeds, in contrast, germinated prior to sweet clover. Fremont cottonwood seedlings were overtopped by sweet clover during early summer, but they were exposed to full sunlight after the midsummer death of sweet clover and had high survivorship. This suggests a possible management strategy for salt cedar, at least within small areas. If native annual species were identified that germinated after (or simultaneously with) native trees but prior to salt cedar, it might be feasible to disperse seeds of the annual herb into the floodplain at an appropriate time after large floods. However, care should be taken to insure that such an effort would reduce abundance only of salt cedar and not of “desirable” summer-germinating species such as seep willow.

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