

Tamarisk and River Restoration Along the San Pedro and Gila Rivers

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Abstract—The abundance of tamarisk (*Tamarix ramosissima* and related species) along the San Pedro and Gila River flood plains varies with differences in stream flow regimes. Tamarisk abundance, relative to Fremont cottonwood and Goodding willow, is greater at sites with more intermittent stream flows and deeper and more fluctuating ground-water levels. Tamarisk abundance is further increased below Coolidge Dam, where both flood and low flow patterns have been altered. Shifts from cottonwood-willow to tamarisk parallel other changes in the riparian community: as rivers are dewatered and flood regimes altered, species diversity and landscape heterogeneity decline. Tamarisk dominance can be seen as an indicator, rather than a cause, of riparian degradation, reflecting changes in the physical processes that shape riparian plant communities. Restoration strategies should focus on identifying and alleviating these underlying environmental stressors to produce long-lasting results.

Introduction

The biota and physical environment of an ecosystem undergo continuous change. There has been a particularly high rate of influx of new species into riverine habitats, partly due to their intensive use as agriculture lands, urban areas, and transportation routes, and partly due to their intrinsic nature as high-disturbance, linear corridors, whose community composition is largely driven by immigration processes (Brown and Peet 2003). The millions of neotropical migrant birds flying north and south along the San Pedro riparian corridor, for example, transport plant seeds. At the same time, frequent flooding provides for nearly constant flux in resource availability and thus provides frequent opportunities for species replacement (Davis et al. 2000). Thus, many immigrant plant species have become integrated into riparian landscapes (McLaughlin 2004).

Tamarisk (*Tamarix chinensis* and *T. ramosissima*) was introduced to the United States from Asia in the 1800s for soil erosion control and landscaping purposes. Tamarisk now forms a minor component of the riparian landscape mosaic on some western rivers, but on others it has become the dominant vegetation type. Contemporaneous with tamarisk increase has been decline of Fremont cottonwood-Goodding willow (*Populus fremontii*-*Salix gooddingii*) associations on some (but certainly not all; Robert Webb, unpublished data) rivers of the Southwest. Given perceptions of tamarisk's high water use and role in altering ecosystems, there are considerable efforts to control its spread and dominance in western riparian ecosystems. Methods such as burning, herbicide application, mechanical removal, and biologic control via insect herbivores are frequently employed (Quimby et al. 2003).

Correlations observed between tamarisk abundance, low biodiversity, and low abundance of cottonwoods-willows have fostered this species-removal approach to river restoration. However, it can be difficult to distinguish between alterations to an ecosystem caused by a new species (autogenic effects) and those caused by changes to physical processes that facilitated the shift in species composition (allogenic effects) (Stromberg and Chew 2002). A plant species may be a cause of change or it may be a symptom of change; distinguishing between the two is critical for designing restoration plans.

Hydrology and geomorphology are key drivers of vegetation dynamics in riparian ecosystems, and as these physical factors change, so does the biota (Poff et al. 1997). Shifts in hydrologic regimes can alter competitive hierarchies and cause shifts in species composition (Tickner et al. 2001). Thus, consideration of hydrologic regimes and fluvial processes is essential for river restoration projects. Our objectives in this paper are to discuss (1) relationships between hydrologic factors and cottonwood, willow, and tamarisk distribution along the San Pedro River and middle Gila River; (2) ecosystem changes associated with shifts from cottonwood-willow to tamarisk, and (3) relationships between tamarisk management and riparian ecosystem restoration.

Stream Flow Regimes

The flood flow regime of the undammed San Pedro River reflects the climatic signal. Floods occur mainly in winter, late summer, and fall; peak flows of >10,000 cfs occur fairly frequently. The low flow regime ranges from perennial to intermittent to ephemeral. The location of perennial reaches varies depending on proximity to major tributaries, sub-surface

geology, and the extent of ground water pumpage. In perennial reaches, surface flows remain in the channel even during dry seasons, sustained by ground-water inflow from the stream alluvium and regional aquifers. In intermittent areas, surface flow ceases during the months (e.g., May, June; October, November) between rainy seasons. The depth to ground water (averaged across the flood plain) at the intermittent sites can be more than five meters with inter-annual fluctuation of more than one meter. At the driest sites, flow is present only for a few days each year following run-off events. Intermittent-flow reaches are prevalent in the Lower Basin downstream from areas of ground-water pumping for agricultural and copper mining uses, and also occur in the Upper Basin, such as below the St. David diversion structure.

Flows in the middle Gila River (San Carlos Lake—Ashurst/Hayden Diversion Dam) are influenced by the operation of Coolidge Dam. In the below-dam reach, river flow is maintained during most years by scheduled releases for downstream agriculture users. Steady releases for irrigation can cause alterations in channel morphology (Graf et al. 2002), and the Gila River through this reach appears to have narrowed and deepened to carry higher spring and summer base flows (Paradzick unpubl. data). Inflow from the Lower San Pedro River, about 25 km downstream of the dam, contributes some water. However, when water levels in the San Carlos reservoir are low, due to drought and high levels of diversion and pumping by upstream water users, flow releases from Coolidge Dam can cease. The flood regime also has been greatly altered. Prior to dam closure in 1928, annual flood peaks frequently exceeded 10,000 cfs and sometimes exceeded 100,000 cfs. Since that time, other than a large release in 1993 (29,300 cfs), peak flows have been small (typically <1,000 cfs) immediately downstream of the dam. The disturbance affects of flood flows entering from the San Pedro River apparently have been damped (i.e., reduced flood-plain scouring and inundation) by channel adjustments described above (Paradzick unpublished data).

Abundance Patterns of Tamarisk, Cottonwood, and Willow

Tamarisk distribution and abundance should be considered within the context of the underlying physical and biological processes that shape the ecosystem. The abundance of tamarisk varies over the length of the San Pedro River in tandem with site hydrology, with the species on this river essentially serving as an indicator of low water availability. As well, its abundance differs between the free-flowing San Pedro and flow-regulated Gila River. Differing patterns of abundance of tamarisk, cottonwood, and willow along these rivers reflect the varying responses of these species to environmental influences, at life stages from seedlings through adults.

Tamarisk, Fremont cottonwood, and Goodding willow all are pioneer species that establish in open areas. A typical pattern on Southwestern North American free-flooding rivers is for large winter floods to scour and redeposit flood-plain sediments, creating a patchwork of potential seed beds for plants

to establish without competition from an existing overstory. Receding flows in spring moisten the bare sediments during the brief window when viable seed of the cottonwoods and willows are present. Continued flow recession during late spring and summer creates opportunities for the later-seeding tamarisk to establish. However, where cottonwood and willow seedlings are present, they can reduce the growth rate of intermixed tamarisk seedlings. Field and pot studies have shown that as a seedling, tamarisk, a stress-tolerant species, is not a strong competitor against co-establishing cottonwoods (Sher and Marshall 2003). Often, a negative relationship exists between the ability of plants to tolerate abiotic stress and the ability to compete (Grime 1979).

Cottonwood and willow are the dominant tree species in the flood plains of perennial and wet-intermittent reaches of the San Pedro River, given the presence of suitable hydrologic conditions for their establishment and survival (Lite and Stromberg, in press). In these wet reaches, rates of flood water recession and water table decline during recruitment years remain within tolerance ranges (Shafroth et al. 1998). Over time, the flood-plain surfaces vegetated by cottonwood and willow aggrade during depositional flood events. Depth-to-ground water under the mature forests typically remains less than about three meters, with less than one meter inter-annual fluctuation, which prevents mortality from drought in these drought-sensitive species (Horton et al. 2001). At these perennial river sites, tamarisk occurs as a slow-growing understory component of the cottonwood-willow forests (and see Lesica and Miles 2001). It also forms discrete patches in the flood plain, typically on surfaces that have slightly deeper ground water than those supporting cottonwoods and willows.

As flows become increasingly intermittent and ground water deepens, conditions become less suitable for cottonwoods and willows and more suitable for tamarisk. Lite and Stromberg (in press) have defined hydrologic thresholds at which dominance shifts from cottonwood-willow to tamarisk along the San Pedro River. Cottonwood and willow were dominant at sites where surface flow was present more than 74% of the time, inter-annual ground-water fluctuation was less than 0.5 m, and average maximum depth to ground water was less than 2.7 m, during a two-year period of hydrology data collection. Tamarisk was dominant, with cottonwood and willow absent or sparse, where flow permanence was less than 46%. The three species were co-dominant at the intermediate range of hydrologic conditions. This compositional shift largely reflects interspecific differences in tolerance ranges. Compared to Fremont cottonwood and Goodding willow, tamarisk is deeper rooted and more drought tolerant, and less susceptible to canopy dieback from declining water tables. Along a gradient of dependency on ground water, willow is considered to be an obligate phreatophyte and tamarisk to be a facultative phreatophyte, with cottonwood falling in between. Thus, tamarisk can dominate at dry sites that exceed the environmental tolerance ranges of cottonwood and willow (Busch and Smith 1995).

Changes in the flow regime below dams also influence the relative abundance of tamarisk, cottonwood, and willow, as evidenced by patterns on the Gila River. Tamarisk was first observed along the Gila River in 1916 (on a denuded flood

plain after a large flood; Robinson 1965) and became abundant by the 1940s and 1950s. From there, it may have spread up the San Pedro River, where it became abundant in the 1950s. Today, tamarisk is more abundant on the flow-regulated Gila River than on the Lower San Pedro, likely due to hydrologic differences between the rivers. Paradzick (unpublished data), in a study of a 38 km reach below Coolidge Dam, found that tamarisk was the dominant patch type in the flood plain, with cottonwoods and willows sparse (figure 1). This likely reflects the combination of altered flood regimes, high-base flow and concomitant channel morphological changes, and fluctuating ground-water levels.

Reduced flood magnitude, suppression of spring flooding, and rapid decline of flood waters have contributed to reduced rates of recruitment of cottonwood and willow along some dammed rivers throughout Western North America (Rood and Mahoney 1990), although on some river reaches populations have remained stable or undergone short-term population increases. Tamarisk, in contrast, often increases below dams, partly because of its opportunistic reproductive strategy. Because it disperses seeds over a longer period, it can thrive in human-altered landscapes where the flood pattern differs from the climatic norm. For example, below-dam increases in tamarisk have been observed on the Verde River, apparently associated with high summer flows for delivery to downstream water users (Beauchamp and Stromberg, unpublished data). With reduction in the intensity and frequency of scouring floods, the cover of tamarisk, and overall density and coverage of woody riparian vegetation across the flood plain, can increase (Shafroth et al. 2002).

Tamarisk abundance patterns along these rivers also may be influenced by land use factors. For example, even when considering only wet sites, tamarisk patches are more abundant in the Lower Basin than Upper Basin of the San Pedro River. This may reflect basin differences in land use history. Past decades of intense livestock grazing may have contributed to high tamarisk abundance in the Lower Basin. When livestock are grazing in riparian seedling beds, they clip the stems of the cottonwoods and willows, which can cause them to lose their height and growth rate advantage to the less palatable tamarisk. Or, wet reaches in the Lower Basin may have been

drier in past decades, contributing to high tamarisk abundance in older age classes (Stromberg 1998a).

Forest composition also is influenced by the rate of forest turnover. Flood intensities (measured as total stream power of various return-interval floods) increase with distance downstream along the San Pedro River as watershed size increases but then peak in the upper end of the Lower Basin as stream gradients decline (Lite 2003). This has allowed for greater flood-related turnover of the pioneer forests in the Lower Basin, where the cottonwood, willows and tamarisk populations all are relatively young. In the Upper San Pedro, there is an abundance of old cottonwoods (which pre-date the oldest tamarisk), thus contributing to high relative abundance of cottonwood-willow relative to tamarisk. Tamarisk has not yet reached its maximum life-span on the San Pedro (Stromberg 1998a).

Landscape Heterogeneity, Biomass Structure, and Species Diversity

From a landscape perspective, river flood plains can be viewed as mosaics of patches, each supporting a different vegetation type reflective of particular hydro-geomorphic characteristics. Studies on the San Pedro indicate that patch heterogeneity increases both as a function of flood intensity and stream and ground-water availability (Bagstad et al., unpublished data). As floods of high velocity and shear stress exceed the thresholds for vegetation removal, certain vegetation patches are destroyed, followed by development of new patches that have a different species composition or age structure. With declines in water availability along the San Pedro, the patch diversity declines, despite the active flood regime. Patches maintained by shallow ground water, such as seep-willow (*Baccharis salicifolia*) shrublands and cottonwood-willow forests, “drop out,” leaving only patches dominated by deep-rooted or drought-tolerant species such as mesquite (*Prosopis* spp.), burrobrush (*Hymenoclea* spp.), and tamarisk (figure 1). The trend toward homogeneity is more evident on the Gila River, where periodic drought, flood

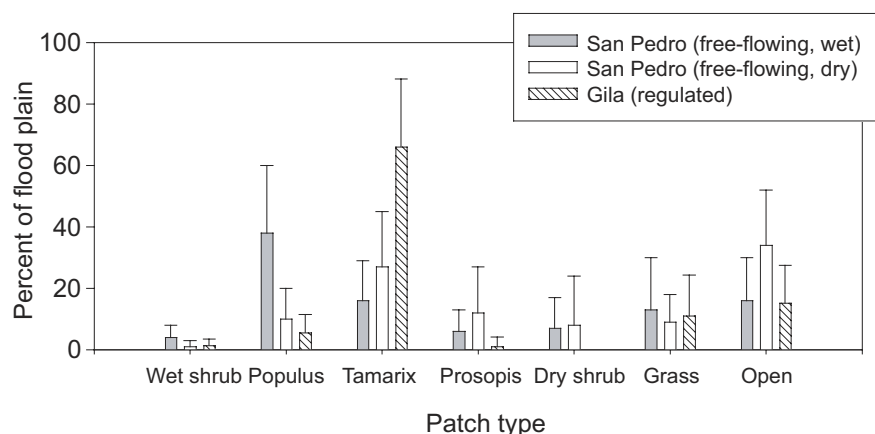


Figure 1—Relative abundance of patch types within the flood plain of the free-flowing San Pedro River (Lower Basin) and the flow-regulated Gila River. Patch types are wet shrublands (*Baccharis salicifolia*, *Salix exigua*), *Populus-Salix* patches, *Tamarix* shrublands, *Prosopis* patches, dry shrublands (*Hymenoclea monogyra*), grass-forblands, and open patches (those with <25% cover in ground, mid-story, and canopy strata). The San Pedro sites were classified into wet (>70% flow permanence) and dry (<70% flow permanence) categories, based on data collected over a two-year period. Values shown are means (and standard error) of 6 to 10 sites per river type.

reduction, and geomorphic changes associated with river damming have created a more homogenous landscape (figure 1). The patch structure is simplified compared to that of the Lower San Pedro River, its major tributary.

There also are changes in vertical biomass structure at dry sites. As composition shifts from cottonwood-willow to tamarisk across spatial gradients of water availability, structure of the riparian forest changes accordingly, reflecting the different growth forms of the species. Along the San Pedro River, average canopy height declined from 23 meters to 13 meters, vegetation volume in upper (above eight meters) canopy layer declined, and woodlands gave way to the shrubland structure type, from perennial to dry-intermittent sites (Lite and Stromberg, in press). These structural changes, together with reduced patch diversity, can reduce wildlife habitat. Tamarisk dominance is not the ultimate cause of the altered wildlife habitat, rather, it is the proximate manifestation of a shift towards a more xerophytic growth form resulting from declines in the resource base. On dynamic, wet river reaches, the complexity of structural types, inclusive of tamarisk patches, creates a habitat-rich area. Many bird species, including the southwestern willow flycatcher, utilize tamarisk patches for nesting and feeding (Paradzick and Woodward 2003; Yard 2003).

The combination of ample water and active flood regimes results in high plant species richness in riparian ecosystems. As flows become more intermittent and ground-water tables decline, there is loss of obligate and facultative wetland herbs and woody hydrophytes (Lite et al., unpublished data). Plant species richness also can be altered by dams. Below-dam richness can increase in some contexts, but also can decline in response to reduced flood disturbance (and reduced temporal and spatial heterogeneity) or to reduced resource availability (e.g., reduced water and nutrient holding capacity of silt-poor soils). Several reviews have reported low biodiversity in tamarisk patches or ascribed other community changes to tamarisk (e.g., Di Tomaso 1998). However, these findings are largely based on studies conducted on dammed and flow-regulated rivers, where species effects are confounded by effects due to changes in the physical processes that regulate species diversity.

Few studies have compared biodiversity levels between vegetation patches on free-flowing rivers. On the San Pedro River, an interesting pattern emerged wherein herbaceous species richness was higher in tamarisk than in cottonwood patches, while woody species richness was higher in cottonwood-willow patches (Bagstad et al., unpublished data; Stromberg 1998b). As well, the understory of the tamarisk had a lower percentage of introduced species than did cottonwood patches. Although this latter pattern is consistent with the lower (and wetter) fluvial surfaces of the cottonwood patches, one also would expect the lower lying cottonwood patches to have higher richness of understory species. However, many factors influence species diversity. The dense canopy (and dense litter layer) of the cottonwood forests may preclude establishment of small-seeded species, and produce a depauperate herbaceous understory, while favoring survivorship of the often larger seeded tree species. Differences in soil mycorrhizae populations between

Fremont cottonwood and tamarisk patches, a topic that warrants further study, also may come into play.

Riparian Ecosystem Change and River Restoration

Various conceptual models exist to explain recent changes in Southwestern riparian communities (figure 2). One model places tamarisk as the main driver of biotic changes, by modifying the resource base and disturbance regime. However, the supporting evidence for such changes (including river salinization and dewatering), when one traces the citation trail, is very sparse, or is not substantiated by recent research. Recent reviews (Glenn et al., unpublished data), for example, demonstrate how measured rates of tamarisk evapotranspiration have declined over time as methodologies have improved; rates of tamarisk evapotranspiration now are viewed as being on par with many Sonoran riparian species, with a water use of about 1 m per year. With respect to salinization of flood plains, unsubstantiated and perhaps erroneous conclusions have been drawn (e.g., Walker and Smith 1997) by confounding the *correlation* between halophytic tamarisk and saline habitats with *causation*. On one free-flowing river, differences in soil salinity between cottonwood-willow and tamarisk patches were not evident (Bagstad et al., unpublished data; Stromberg 1998b). On regulated Southwestern river systems, salt accumulation on the soil surface could be a combined effect of tamarisk exudation and lack of flushing flood flows, as some have speculated (Shafroth et al. 1995), but this has not been rigorously investigated.

An alternative model places humans as the primary cause of the vegetational shifts from cottonwoods-willows to tamarisk, by altering flood patterns, water quantities, and water quality (figure 2). Certainly, all plants modify their environments; the presence of tamarisk as a competitor likely restricts cottonwoods and willows from areas of marginal habitat. However, there is considerable evidence that tamarisk dominance is part and parcel of a suite of changes associated with river flow management: dewatering causes declines in species biodiversity and landscape heterogeneity and drives compositional shifts toward drought tolerant species, while dam operation further contributes to reduced heterogeneity and diversity. Thus, the dominance of tamarisk can be viewed as an indicator, rather than a prime cause, of degradation, that reflects alterations to the biophysical factors and processes that control riparian ecosystem structure.

If one fails to address the root causes of riparian vegetation change, the desired end product likely will not be attained, and adverse effects could result from ecosystem manipulations. On diverted or regulated streams, where there is a clear decline in the fundamental resource base or disturbance regime, restoration of flow regimes is warranted. Many restoration efforts, however, simply involve “weeding” tamarisk from flood plains. By clearing tamarisk from such reaches, without increasing water resources or modifying disturbance regimes, one may further reduce the quality of the habitat depending on what plant species are available to replace the tamarisk patches.

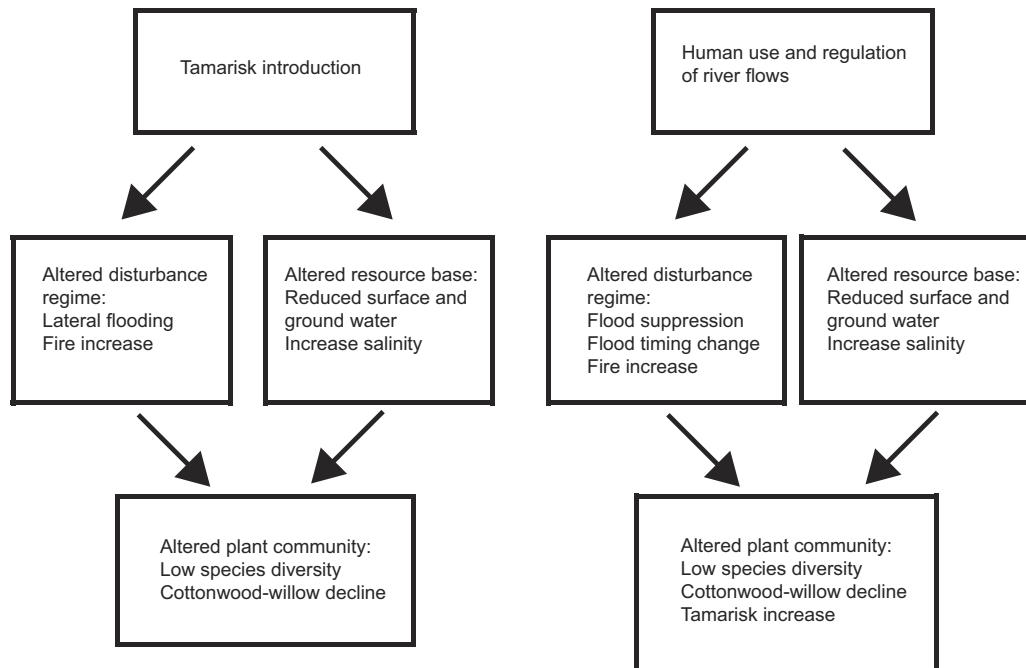


Figure 2—Alternate conceptual models of the primary factors driving changes in riparian plant communities of Southwestern river flood plains.

On free-flowing, perennial, ungrazed rivers, restorative efforts (including tamarisk weeding) likely are not needed. When an introduced species such as tamarisk is simply one of a mixture of species in a diverse riparian plant community, there does not appear to be any compelling reason, other than aesthetic, to engage in tamarisk removal efforts.

It is fundamentally more difficult to restore river flows or “re-wild” rivers than it is to rally efforts around removing an unwelcome species. There are a few notable cases where rivers are being re-watered for restoration purposes. Among these is the San Pedro, which has become a mitigation site for regional riparian degradation, resulting in local reductions in rates of ground water pumping from the stream aquifer. Monitoring of changes in species diversity, landscape heterogeneity, and cottonwood, willow, and tamarisk abundance, in response to river re-watering, will provide an interesting test of our knowledge of riparian plant-environment relationships.

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