

Exhibit 5

FRÉMONT COTTONWOOD-GOODDING WILLOW RIPARIAN FORESTS: A REVIEW OF THEIR ECOLOGY, THREATS, AND RECOVERY POTENTIAL

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ABSTRACT

Gallery forests of *Populus fremontii* Wats. and *Salix gooddingii* Ball historically were one of the most abundant riparian ecosystems along low-elevation rivers of the southwestern United States and northern Mexico, and now are among the most threatened forest types in the United States. Manipulation of water resources and fluvial processes pose some of the greatest threats to Sonoran cottonwood-willow systems, with other threats to these species-rich ecosystems coming from land uses such as livestock grazing and sand and gravel mining. The reproductive biology of Frémont cottonwood and Goodding willow is strongly tied to fluvial processes, with seedling recruitment of both species dependent upon periodic flood flows to deposit and moisten alluvial sediment bars. Mature plants often become isolated on high floodplains some distance from the active channel, but continue to remain hydrologically dependent on a shallow riparian water table. Restoration and preservation of these species-rich forests depends upon removal of activities which interfere with natural ecosystem processes (e.g., livestock which destabilize and erode recruitment bars; dams and diversions that lower water tables and prevent channel meandering and sedimentation).

INTRODUCTION

Gallery forests of *Populus fremontii* Wats. and *Salix gooddingii* Ball occur along floodplains of low-elevation rivers of the southwestern United States (Arizona, California, Utah) and northern Mexico. They historically covered hundreds of kilometers along lower reaches of rivers such as the Colorado, Gila, Rio Grande, Rio Yaqui, Salt, San Miguel, San Pedro, and Santa Cruz (Grinnell 1914; Brown 1982; Minckley and Rinne 1985). Today these Sonoran riparian cottonwood-willow forests are among the most threatened forest types in the United States (Swift 1984; Anonymous 1989). Some stands are protected on private land (e.g., the Nature Conservancy's Hassayampa River Preserve) or public land (e.g., the San Pedro National Riparian Conservation Area), but human activities continue to threaten many of these unique environments which serve such important roles as habitat for neotropical migratory birds. This paper summarizes the plant ecology of Frémont cottonwood-Goodding willow associations, reviews threats to their existence, and discusses their recovery potential. Summaries of animal ecology of these associations can be found in Ohmart and Anderson (1986) and Rosenberg *et al.* (1991).

ECOLOGY

Habitat. --Frémont cottonwood-Goodding willow forests occur along floodplains of large, low gradient (<0.005 ± 0.002 m/m; Szaro 1989, 1990), perennial streams in wide, unconstrained valleys, such as Rosgen's (1985) type C or type D streams. In Arizona, such streams are usually below 1250 m elevation. Optimal conditions for forest development are along depositional environments, where fine-grained alluvial substrates are present in the floodplain. Such streams often have multiple historic and/or active channels which undergo continual lateral adjustment, as they meander and form new alignments.

Sonoran cottonwood-willow forests often occur with other riparian types (Lacey *et al.* 1975; Brown 1982) because fluvial processes such as channel meandering and floodplain aggradation create environmental gradients and mosaics (e.g., depth to water table, frequency of inundation) that favor a diverse assemblage of riparian species. These assemblages may include: *1*) Sonoran interior marshlands, dominated by *Typha*

spp. (cattail), *Scirpus* spp. (bulrush), or other emergents; 2) Sonoran riparian scrubland, variously dominated by *Baccharis salicifolia* (R&P) Pers. (seepwillow), *Hymenoclea* spp. (burro brush), *Tessaria sericea* (Nutt.) Shinners (arrowweed), *Suaeda torreyana* Wats. (seepweed), or *Atriplex* spp. (saltbush); and 3) *Prosopis* spp. (Sonoran riparian mesquite) forests. Plant names follow Lehr (1978). The various riparian types often intermix forming complex spatial patterns. The mature cottonwoods and willows, which reach 30 m in height and 3 m in diameter, tower above the other riparian species and above the surrounding desertscrub or semi-desert grasslands.

Vegetation structure. --Tree species diversity of the Sonoran cottonwood-willow forests is low. In addition to Frémont cottonwood and Goodding willow (which may or may not be codominant), the forests contain few other deciduous trees, notably *Fraxinus pennsylvanica* Marsh ssp. *velutina* (Torr.) G. N. Miller (velvet ash) or *Prosopis pubescens* Benth., *P. glandulosa* Torr. var. *torreyana* (Benson) M. C. Johnston, or *P. velutina* Woot. (screwbean, western honey, velvet mesquite, respectively) (Brown 1982; Szaro 1989). Overstory cover and basal area of the gallery forests are generally high (85% and 18 m²/ha, respectively; Szaro 1989). Tree densities range from 50 to 800 stems/ha (Stamp 1978; Hunter *et al.* 1987; Szaro 1989).

Whereas tree species diversity is low, age class and structural diversity are high. Cottonwood and willow stands often consist of spatially separate, same-age cohorts that grow in linear bands parallel to the primary or secondary channels (Stromberg *et al.* 1991). The youngest cohorts are closest to the channel, while the older trees can be found on floodplains up to 200 m from the primary channel. These patterns have been described as arcuate bands, or "isochrones" of trees (Everitt 1968; Bradley and Smith 1986). Young cohorts are most abundant. Brady *et al.* (1985), for example, found densities (per ha) of up to 200,000 seedlings, 8,000 saplings, 1500 submature trees and 500 mature trees along the San Pedro River. Cottonwoods and willows at the Nature Conservancy's Hassayampa River Preserve (Maricopa Co., Arizona) also decrease in abundance with age, with ca. 12,000 saplings, 1100 small trees, and 140 mature trees per ha (Stromberg, unpublished data). Trees typically have a lifespan of 100 to 150 years (Strong 1982; Stromberg *et al.* 1991; Stromberg 1993).

The understory of mature cottonwood-willow stands can be dense or open and park-like depending on past history of flooding or other disturbance. In Arizona, the shrub and small tree stratum often consists of seepwillow and young mesquite. *Sambucus mexicana* Presl. (elderberry), *Rhamnus* spp. (buckthorn) and *Tamarix pentandra* Pall. (the exotic saltcedar) also may be present (Szaro 1989). In New Mexico, *Elaeagnus angustifolia* L. (the exotic Russian olive) has become a common understory tree in cottonwood-willow forests (Campbell and Dick-Peddie 1964).

The herbaceous understory of most cottonwood-willow stands has been altered by grazing and other factors, and thus its original composition and cover is difficult to ascertain. Often, the cottonwood-willow forests support a more diverse understory assemblage than do other adjacent riparian types. Most understories contain a mix of perennials and annuals, and of exotic and native species (Campbell and Dick-Peddie 1964; Rucks 1984; Szaro 1989; Wolden 1993). Cool-season plants include various native annuals (*Bowlesia incana* Ruiz and Pavon and *Amsinckia* spp.) and exotic annuals (species of *Bromus*, *Hordeum*, *Schismus*, *Sisymbrium*, and *Erodium*). Warm-season natives include annuals such as *Amaranthus palmeri* Wats. (pigweed) and perennials such as *Cucurbita* spp. (coyote melons), *Distichlis spicata* (L.) Greene (saltgrass), *Muhlenbergia rigens* (Benth.) Hitchc. (deer grass), and *Anemopsis californica* (Nutt.) H. & A. (yerba mansa). Warm season exotics include the perennial *Cynodon dactylon* (L.) Pers. (Bermuda grass).

Reproductive ecology of Frémont cottonwood and Goodding willow. --Cottonwoods and willows are pioneer species, and have many features that allow for colonization of disturbed areas. Both produce prolific numbers of small seeds at a young age. For example, *P. deltoides* Marshall, a closely related species, begins producing seeds at the age of 5 to 15 years and when mature each tree produces about 25,000,000 seeds/yr, each of which are about 1 mm long (Bessey 1904). The seeds have "tufts" of trichomes, adaptations for long-distance wind or water dispersal (Fenner *et al.* 1985). Frémont cottonwood and Goodding willow establish mainly from seed rather than asexually, although both can sprout shoots from lateral buds on stems prostrated by flood flows, *i.e.*, Everitt's (1968) "flood-training."

Flooding is the primary disturbance in cottonwood-willow systems, and germination and establishment of the trees coincide with flood events. *Populus deltoides*, for example, recruits during years when

maximum daily flows during seed dispersal equal or exceed the magnitude of a flood within a two-year return interval (Bradley and Smith 1986), while *P. angustifolia* James establishes about once every 10 to 15 years, in years with high spring discharge (Baker 1990). Tree-ring studies within the Hassayampa River system indicate that Frémont cottonwood and Goodding willow also establish on a large scale about once a decade, during or after years with flood flows greater than or equal to the 7-year return event (>250 cms) (Stromberg *et al.* 1991; Stromberg, Richter *et al.* 1993). On Sonoita Creek and the Santa Cruz River in southern Arizona, long-term fluctuation in the occurrence of large winter or spring floods has resulted in several decades without Frémont cottonwood establishment (Stromberg, Sommerfeld *et al.* 1993; Stromberg 1993).

Several factors restrict germination of Frémont cottonwood and Goodding willow to spring and early summer. These include: early spring dispersal, short periods (1-5 weeks) of seed viability, and rapid seed germination (24-48 hours). These phenological adaptations help synchronize germination with the period of high spring flows, which are often above base level in spring due to snow melt and runoff from episodic winter or spring rainstorms (Fenner *et al.* 1984, 1985; Reichenbacher 1984; Siegel and Brock 1990). Germination during high flow conditions increases the probability that seedlings will establish on floodplains that are above the zone of frequent subsequent flooding.

Moist, unvegetated mineral soil or alluvium is necessary for germination and establishment of Frémont cottonwood and Goodding willow and other related species. Soil water potentials of >6 atm. results in delayed and reduced germination, and dense herbaceous cover prevents seeds from making physical contact with the soil (Noble 1979; Fenner *et al.* 1984). Moistening of the soil or alluvium is accomplished by spring overbank flows or, in areas with shallow water tables, by capillary wetting of the surface soils. Clearing of near-stream vegetation and deposition of alluvium are both products of flood flows. A ten-year return flood along the Hassayampa River, for example, deposited an average of 8 cm of sediment throughout the floodplain, with greater amounts deposited on recruitment zones (Stromberg, Richter *et al.* 1993).

Frémont cottonwood and Goodding willow have slightly different regeneration niches. Compared to the cottonwoods, Goodding willows tend to establish on floodplain sites that are slightly closer to the stream and closer to the water table. These patterns result from differences in moisture tolerances (with willow seedlings having higher tolerance for saturation than do cottonwood seedlings; Walters *et al.* 1980) and in timing of seed dispersal and germination, *i.e.*, in emergence phenologies. Goodding willow seeds disperse and germinate about a month later in spring than Frémont cottonwood seeds, during a time when the stream waters have receded somewhat and the moist germination band is closer to the stream (Stromberg *et al.* 1991).

Main causes of mortality for cottonwood and willow seedlings are drought and summer or fall floods (McBride and Strahan 1984). Although both species can sprout shoots from lateral buds on flood-prostrated stems, seedlings that germinate too close to the low flow channel have a high probability of death from flood scour or sediment burial (Stromberg *et al.* 1991). Frémont cottonwood seedlings are somewhat more tolerant of drought than are Goodding willow, but moist soils throughout the growing season are a necessity for establishment of both species; a soil moisture content of about 10% is believed to be a minimum for survivorship of seedlings (Pope 1984). Rapid root growth increases the probability that seedlings that established at a high-water line will develop sufficiently deep roots to tap into groundwater or capillary water before the return of base flow conditions. Roots of Frémont cottonwood seedlings can grow 6-13 mm/day and thus most seedlings could tap water at ca. 0.7 m depth by the end of summer (Fenner *et al.* 1984; Pope 1984; McBride *et al.* 1988). Rapid water table decline, however, may result in seedling mortality particularly for willows (McBride *et al.* 1988). Cottonwood seedlings have optimum growth and survival when the rate of water table decline is less than 3 cm per day (Mahoney and Rood 1991).

Growth and survival of Frémont cottonwood and Goodding willow. --Water availability is one of many factors (*e.g.*, nutrient availability, flood scour, tree density, beaver foraging) that influence growth and survival of mature cottonwoods and willows. For example, annual diameter growth of *P. deltoides* was shown to vary from about 2 cm/yr in drier habitats to 7 cm/yr in wet habitats (Fowells 1965). In some riparian systems, annual radial growth rate of cottonwood increases nearly linearly with volume of surface flow (Stromberg and Patten 1990, 1991). This relationship occurs despite the fact that cottonwood and

willow trees often become isolated at distances of up to hundreds of meters from the primary channel (because of channel meandering or realignment) and at heights of up to several meters above the streambed (because of sediment deposition during flooding or incision of the stream channel) (Everitt 1968; Lacey *et al.* 1975; Irvine and West; 1979; Reichenbacher 1984; Stromberg *et al.* 1991). Several studies have indicated that such floodplain trees remain hydrologically connected to the channel, and have demonstrated tight linkages between the riparian water table and the channel surface flow volume (Stanford and Ward 1988; Busch *et al.* 1992).

Mature cottonwood and willow trees survive these dynamic changes by possessing lateral surface roots as well as moderately deep roots (about 3 m; Zimmerman 1969) that extend into the water table. Early work indicated that Frémont cottonwood utilized water from the unsaturated zone of soil water (McQueen and Miller 1972), but recent stable isotope studies have shown that cottonwood and willow both uptake water that arises from the saturated zone, *i.e.*, groundwater. However, cottonwood and willow are more limited in their ability to extract water from great depths than are deeper rooted riparian species such as mesquite. Typical depths to groundwater within Fremont cottonwood - Goodding willow systems are less than 5 m although some greater depths have been reported. Along the Colorado River and Bill Williams River, mean growing season water table depth ranged from 1.2 ± 0.3 to 3.5 ± 0.5 among sites (Busch *et al.* 1992). Along the Hassayampa River, depth to groundwater increased from 1.0 ± 0.3 m for 10-year-old trees to 2.6 ± 0.6 m for 40-year-old trees (Stromberg *et al.* 1991). Depth to groundwater along the San Pedro River was 0.3 to 2.3 m for young, near-stream trees and about 4 m for the largest trees (ca. 2.0 m dbh) (Jackson *et al.* 1987). Depth to groundwater along Sonoita Creek was about 1 to 1.5 m for 10 to 15 year-old Frémont cottonwood trees, and about 2.5 m for the oldest, 130 year-old cohort (Stromberg, unpubl. data).

Relationships between nutrients and growth or productivity of Frémont cottonwood and Goodding willow have not been quantified, nor have primary riparian nutrient sources been identified. Nitrogen is known to be limiting in many southwestern aquatic systems (Grimm and Fisher 1986), but this may not necessarily be true of the riparian system since it can serve as a nutrient filter, taking up large quantities of nutrients from upland runoff before they reach the aquatic system (Lowrance *et al.* 1984). Within the riparian floodplain itself, litter deposited by nitrogen-fixing mesquite trees can serve as an important nutrient source (Klemmedson and Tiedemann 1986). The hyporheic zone, which can extend within the floodplain aquifer for several kilometers from the river channel, also can be a key source of nutrients, and has been found to have greater nutrient concentrations than the river channel itself (Stanford and Ward 1988). Sediment deposited during flood flows is a potential nutrient source, but sedimentation also can deplete surface nutrient levels particularly in regulated rivers (Stevens and Waring 1988; Junk *et al.* 1989).

With respect to mortality factors, flood flows, although integrally related to recruitment of cottonwood and willow, deserve mention. Along the Nature Conservancy's Hassayampa River Preserve, survivorship of saplings and small cottonwood and willow trees varied as a function of flood magnitude, although survivorship was relatively high for even the largest flood event monitored (10-year flood) (Stromberg *et al.* 1991). Anecdotal reports indicate that a >100-year flood event near the turn of the century removed many trees, which would explain the absence within the Hassayampa River floodplain of trees >100 years-old. Mortality from large floods has been found to be high in other riparian systems, although in most cases the floods have been altered because of upstream flow management (Hunter *et al.* 1987; Stevens and Waring 1988).

HYDROLOGIC THREATS

Threats to cottonwood-willow forests come in many forms. Manipulation of water resources and fluvial processes pose some of the greatest threats to Sonoran cottonwood-willow systems, and may interfere with essential hydrological processes (*e.g.*, flooding); reduce availability of basic abiotic needs (*e.g.*, water or nutrients); or cause direct mortality. These anthropogenic activities including groundwater pumping; damming, diversion and regulation of surface flow or of effluent; and interbasin transfers of groundwater or surface flow.

Dams and diversions.—Sonoran riparian systems have evolved with, and depend upon natural processes innate to Southwestern streams (Reichenbacher 1984). Dams and diversions on perennial streams modify many of these processes, including sediment deposition, flooding, stream meandering, and perennial water availability, with substantial impacts to downstream riparian communities. Small dams and diversions along rivers have been common in the Southwest as far back as the Hohokam (AD 800) who farmed in the Salt River Valley near present-day Phoenix. The 20th century, however, created a much greater demand for an assured supply of water for agricultural and urban water needs and for hydropower; as a consequence, most of the large rivers in Arizona are dammed and/or diverted (Anonymous 1989).

In cases where water is diverted out of the channel, the amount of water released downstream will be less than the natural flow volume. In some cases, such as on the lower Salt River in Arizona, no water is released down stream during low or normal hydrological years. In other cases, cumulative impacts of small diversions can substantially reduce base flows. This is the case for portions of the upper Verde River, with water use models projecting a flow reduction of up to 25 hm³ (20,000 acre feet) per year by the year 2025 (Moore 1989). Because instream flow requirements are relatively high for cottonwoods and other riparian trees (Stromberg and Patten 1990), even partial diversion can result in riparian vegetation decline (Stine *et al.* 1984; Brock 1987). Temporary periods of low or no flow release from impoundments also may cause tree death. For example, 46% to 84% of the Frémont cottonwoods at a site along the Verde River died during a dry period in the 1970's, due to a combination of low flow release from Bartlett Dam and groundwater pumping from the Verde River Infiltration Gallery and Well Facility (McNatt *et al.* 1980). Many willows including Goodding willow are even less tolerant of water reduction than are Frémont cottonwood (*e.g.*, McBride *et al.* 1988). These differential tolerances can result in compositional shifts of the below-dam riparian community (Nilsson 1982).

Although construction of dams and large-scale diversions has slowed in recent years (Beaumont 1978), many riparian areas face a new threat of diversion of effluent from the stream channel (Tellman 1992). This approach, which is being considered by many municipalities as an alternative to meeting more stringent federal water quality standards, can result in decline or elimination of the riparian vegetation (Jones and Snyder 1984). Potential impacts are great because of the large number of riparian systems either totally dependent upon (*e.g.*, portions of the Salt River) or have their flows supplemented by municipal-industrial effluent (*e.g.*, portions of the Santa Cruz). An alternative to diverting the effluent is constructing artificial wetlands at the effluent release point, which are considered to be superior to woody riparian vegetation in removing heavy metals and nutrients that often occur in effluent water (Sullivan 1991). However, concern still remains that higher-trophic level species, such as *Rallus longirostris yumanensis* Dickey (Yuma clapper rails), may suffer adverse effects from biomagnification of the toxic materials (Welch and Lindell 1980) within the constructed wetlands.

Riparian ecosystems along rivers that are regulated, rather than diverted, are impacted in more subtle ways. For example, because impoundments decrease water velocity and thus decrease its ability to transport suspended material, sediments and nutrients are deposited in the impoundment rather than being released into the below-dam system. These sediment-depleted flows have increased erosive power which can cause channel degradation (downcutting) and decline in riparian water tables (Bradley and Smith 1984; Williams and Wolman 1984; Jackson and Summers 1988). This can impact cottonwoods, willows and other riparian trees dependent on shallow water tables and on deposition of alluvial recruitment areas, and can lead to eventual loss of the gallery forests (Reily and Johnson 1982; Johnson 1992). Because the age of some dams (*e.g.*, <50 years for Alamo Dam on the Bill Williams River) is young in comparison to the lifespan of the gallery forest (100 to 200 years), impending forest decline may be masked by the apparent vigor of the mature gallery forest (Petts 1985; Howe and Knopf 1991).

Regulated flows often create a new flow regime for the below dam river (Chien 1985). While most normal flow regimes respond to precipitation or snowmelt events, a manipulated regime is a product of factors that control water release (*e.g.*, agriculture and power demands) and may be flatter or have peaks and dips out of synchronization with natural cycles. For example, flow peaks may shift from spring to summer, as a result of flow release only after reservoir filling. Such alteration can prevent establishment of cottonwoods, willows, and other spring-germinating species (Fenner *et al.* 1985; Bradley and Smith 1986;

Rood and Heinze-Milne 1989; Rood and Mahoney 1990). This reduction in diversity of cottonwood and willow size and age classes has adverse effects on abundance and diversity of birds and mammals that utilize particular height strata within the canopy (Ohmart and Anderson 1986). Furthermore, summer or fall high flows tend to favor the exotic saltcedar because of its ability to establish after floods that occur during any part of the growing season (Horton *et al.* 1960). Saltcedar stands, however, have low habitat value for most wildlife because they have low plant species diversity, low canopy height, and low vertical and horizontal complexity (Rosenberg *et al.* 1991).

In the absence of flooding, rates of river meandering and channel realignment often decrease, potentially causing a narrowing of the riparian zone and a decrease in the patchiness and diversity of the riparian habitat. These changes, in turn, can extirpate animal species dependent on a minimum width of the riparian area, such as *Coccyzus americanus* (yellow-billed cuckoo; Reiner and Griggs 1989), as well as generally reduce species abundance and diversity within a habitat renowned for supporting the highest avian abundance and diversity of any within the Southwest (Rosenberg *et al.* 1991).

Sustained flooding also can damage riparian communities. In an extreme case, sustained flooding on the Bill Williams River from 1978 to 1980 (caused by flow releases from Alamo Dam) caused death of nearly all of the cottonwoods (99%) and most of the willows (64%) in some areas (Hunter *et al.* 1987). Death by inundation is also common for Frémont cottonwoods and other riparian species that grow in or near new or expanded reservoirs (Turner 1974).

Groundwater pumping. -- Agricultural areas in the arid West have used groundwater for most of this century, resulting in substantial declines in groundwater depth in many areas (Briggs 1976). Groundwater use by urban areas also is substantial and is increasing in many expanding urban areas, despite availability of new surface water sources such as Central Arizona Project water. In some states, including Arizona, there is as yet no legal connection between groundwater and surface water, despite hydrologic studies indicating otherwise (*e.g.*, Jenkins 1989). Groundwater pumping may reduce the base flow and increase the depth to the riparian water table, potentially resulting in reduced growth and survivorship of trees, reduced riparian stand area, and composition shifts toward more xeric species (McNatt *et al.* 1980; Groeneveld and Griepentrog 1985; Jackson *et al.* 1987; McGlothlin *et al.* 1988). Along the upper Santa Cruz River, for example, groundwater pumping by the City of Nogales and other municipalities is creating cones of groundwater depression that are adversely impacting Frémont cottonwood and other riparian vegetation (Stromberg, Sommerfeld *et al.* 1993).

LAND USE AND OTHER THREATS

Livestock grazing. --Livestock grazing in southwestern riparian systems can have many adverse impacts (Armour *et al.* 1991). Within southwestern cottonwood-willow ecosystems, unregulated livestock grazing has been implicated as a primary causes of decadent age structures, wherein many stands have large, old trees but few saplings or small trees (Brotherson *et al.* 1983; Fenner *et al.* 1984; Rucks 1984; Shanfield 1984). Glinski (1977) documented a correlation between levels of grazing and Frémont cottonwood recruitment, and others have found fewer cottonwood seedlings in grazed vs. ungrazed areas (Crouch 1979; Szaro and Pase 1983; Reichenbacher 1984; Shanfield 1984). Reduced seedling establishment can result from browsing and trampling of seedlings and from reduction of stabilizing herbaceous cover. Although decreased herbaceous cover can increase cottonwood germination rates in the short term (Crouch 1979), without stabilizing streamside vegetation, for example *Paspalum distichum* L. (knot grass), soils become highly erodible during floods (Kauffman and Krueger, 1984) and seedling survivorship declines. Grazing also can result in reduced growth rates of trees (Crouch 1979), in part due to increased soil compaction and resulting reduction in water percolation and abundance of mycorrhizae and other soil symbionts (Donnelly and Shane 1986; Simmons and Pope 1988). Reduction in cover, density or size classes of particular plant species in turn can lead to declines in bird species abundance (Taylor 1986; Sedgwick and Knopf 1987).

Herbaceous understory vegetation in Sonoran cottonwood-willow systems has been substantially altered. This may be due, in part, to long histories of livestock grazing in the Southwest and to the tendency of cattle

to congregate in large numbers in the riparian zones. High frequency of surface disturbance and altered nutrient dynamics in grazed understories may favor disturbance-adapted exotic annuals over native species, and alter the amount of herbaceous cover (Reichenbacher 1984). However, there is a need for more research on grazing effects in aridland riparian systems, similar to that conducted within more mesic regions of the west (see Armour *et al.* 1991).

Land clearing. --Rates of riparian land clearing have declined in recent years, but land clearing for agricultural use still poses a threat to some cottonwood-willow systems, such as those along the lower Colorado River (Ohmart *et al.* 1988). Agricultural use of adjacent land also can affect riparian systems, for example, by exposing salt-intolerant species such as Frémont cottonwood (Jackson *et al.* 1990; Siegel and Brock 1990) to salt-laden agricultural tail water. Clearing of riparian vegetation to increase stream flow (*i.e.*, phreatophyte control; Culler 1970) is no longer an active management practice, and thus poses little threat to cottonwood-willow systems. In its stead, however, removal or reduction of upland vegetation to increase watershed runoff (Brown and Fogel 1987) potentially threatens riparian systems by altering watershed runoff and sedimentation patterns.

Land clearing also can result in fragmentation of riparian habitat. Fragmentation can cause reduced riparian diversity (Hanson *et al.* 1990), as well as declines in abundance and diversity of specific groups of species including neotropical avian migrants that require large continuous tracts of habitat. Fragmentation also can have more subtle effects on riparian species, by causing genetic isolation of once-continuous populations (Brode and Bury 1984).

Watershed degradation. --Processes that reduce upland vegetative cover, such as cattle grazing, vegetation clearing, vegetation conversion (*e.g.*, chaparral to grassland) and fire, can affect riparian systems by altering stream flow regimes and fluvial processes. Reduction in vegetative cover often results in increased overland runoff, thereby increasing the velocities and volumes of flood flows, and the erosive power of the stream (Kondolf and Keller 1991). Some reports, however, suggest that vegetation reduction in the uplands benefits riparian vegetation by increasing stream flows (Ingebo 1971; DeBano *et al.* 1984) and by increasing rates of downstream aggradation and thus the area of cottonwood and willow recruitment sites (Asplund and Gooch 1988). Extensive grazing in the uplands and riparian zones is considered by many to be a contributing factor to the extensive channel downcutting and lowering of water tables that occurred early in this century along portions of the Santa Cruz, San Pedro, Sonoita, and other rivers (Bryan 1925, 1928; Leopold 1951; Hastings 1959; Lacey *et al.* 1975; Glinski 1977).

Mining. --Alluvial riverbeds, such as that along the Verde River in Arizona, provide a ready source of sand and gravel for construction activities. This mining, however, can have multiple impacts to on-site and downstream cottonwood-willow systems. Besides directly destroying habitat, sand and gravel operations can threaten riparian systems by pumping groundwater and altering channel configurations and sediment flow processes. For example, sediment-depleted water flowing from deep pits dug within the channel area can cause incision of the stream bed, erosion of downstream channels and sediment bars, and an increase in channel instability (Rhoads and Miller 1990; Kondolf and Keller 1991). On the other hand, excavation of floodplains can create locally important cottonwood nursery bars along streams such as the Verde River which now have reduced ability to create natural recruitment zones (Stromberg, personal observation). Metallurgical mining also can threaten riparian zones, for example, through accumulation of toxic materials in floodplain sediments (Graf *et al.* 1991).

Road development. --Because riparian areas are natural corridors, they have more than their fair share of roads and railways. Roads, railroad berms, or material displaced during road construction, can interfere with natural fluvial processes. For example, they can constrain the floodplain, thereby increasing flood flow velocity and causing channel downcutting. Channel meandering also may be restricted. These processes may decrease the rate of formation of riparian plant recruitment areas and contribute to decadent riparian stands. For example, a 100-year-old railroad berm and a county road within the Sonoita Creek floodplain in Santa Cruz Co., Arizona, are suspected as causes of the low abundance of young Frémont cottonwood in the riparian zone (Glinsky 1977; Fay 1978; Stromberg 1993).

Recreation. --Riparian areas comprise less than 2% of the land area, but receive disproportional use by recreationsists, particularly when located near urban centers (Turner 1983). High levels of recreation,

be it camping, picnicking, or recreational vehicle use, can result in compacted soil, reduced herbaceous and woody plant cover, and declines in bird species abundance (Manning 1979; Johnson and Carothers 1982). A primary recreational threat to Frémont cottonwood-Goodding willow forests is recreational vehicle use, since most use occurs in open streamside areas (*e.g.*, gravel bars) which are often key seedling recruitment areas (Turner 1983).

Fire. --The functional role and frequency of fires in riparian areas has received little study. Turner (1974:12) states that "the dense seasonally dry vegetation along the Gila River . . . periodically caught fire, but with what frequency cannot be determined." The cambium layer of Frémont cottonwood is known to be damaged by even light burns (Turner 1974), and thus post-fire Sonoran riparian communities tend to be dominated by Goodding willow and the exotic saltcedar, because of their capacity for basal sprouting (Higgins 1981). Although certain bird species, *e.g.*, *Phalaenoptilus nuttallii* Audubon (common poorwill), are abundant in burned riparian areas, bird species density and richness decline after riparian fire, and then increase as the post-fire foliage height diversity increases (Higgins 1981; Rosenberg *et al.* 1991).

Elimination of beavers. --*Castor canadensis* (beavers) were abundant in pre-settlement Sonoran riparian forests (Miller 1961; Minckley and Rinne 1985). Beavers exert strong effects on form and function of these forests, and as such, can be considered as keystone riparian species whose absence results in major modification of the ecosystem. Although they often do not build dams along large, high velocity rivers, dams built by beavers along smaller rivers result, locally, in increases in base flow rates, lateral percolation of water to floodplains, water table height, deposition of sediment, accumulation of organic matter, and nutrient cycling (Ffolliott *et al.* 1976; Apple 1985; Parker *et al.* 1985). These processes create conditions that favor many emergent herbaceous species, result in increased growth and vigor of woody species, and create important habitat for breeding birds and other animals.

In areas where riparian acreage is small or the plant community has been degraded, the ability of beavers to reach an equilibrium with their preferred food supply (small diameter cottonwood and willow) is in question (Clements 1991). However, Beier and Barrett (1987) found local extinction of *P. trichocarpa* Torrey & Gray (black cottonwood) in only 4-5% of the stream reaches studied, while McGinley and Whitman (1985) found that beaver foraging modified the growth form and reproductive potential of *P. fremontii* but did not increase mortality. Strong (1982) also suggested that beaver use did not pose a primary threat to degraded Rio Grande cottonwood forests, in part due to the fact that beaver used a wide variety of other foods including 15 woody and four herbaceous species.

Exotic species. --Presence of exotic plant species is often a symptom of altered ecosystem processes, such as changes in the frequency or types of disturbance. Once established, the exotic species can bring about a new set of ecosystem changes and alter ecosystem function (Vitousek 1990). Several exotic herbaceous species compete with the native understories of cottonwood-willow forests, including Bermuda grass, a perennial rhizomatous grass, and several cool-season annual grasses, such as *Bromus* spp. and *Hordeum* spp. (Rucks 1984; Wolden *et al.* 1990; Wolden 1993). Saltcedar is the main exotic woody species in cottonwood-willow systems in Arizona, as is Russian olive in New Mexico. Invasion of saltcedar, a species with a wide tolerance range for many environmental factors, has been accelerated by human activities that have created a new set of conditions to which saltcedar is adapted -- *e.g.*, summer flooding or no flooding, reduced or altered water tables, high salinity from agricultural tail water, high levels of sediment downstream from grazed watersheds, and high fire frequency (Gary 1965; Warren and Turner 1975; Brown 1982; Busch *et al.* 1992). Saltcedar is particularly abundant on regulated rivers, and occupies extensive areas along the borders of reservoirs. Saltcedar can rapidly dominate such riparian habitats, further excluding cottonwood, willow, and many other native species by autogenic processes which can increase soil salinity and fire frequency (Everitt 1980; Busch and Smith 1993).

Exotic animal species also pose local threats to cottonwood-willow systems. Along the Santa Maria River, for example, feral burros have caused the death of many young cottonwoods by stripping their bark and cambium (Matt Peirce, personal communication).

RECOVERY AND RESTORATION

Cottonwood-willow forests have high resilience to some perturbations, because of their functional role as rapidly growing pioneer species (Stromberg and Patten 1989). Thus, degraded systems can naturally recover if hydrological processes are restored, nearby colonization sources are present, and unnatural perturbations are removed (Briggs 1993). For example, seedlings of cottonwood, willow, and other riparian trees tend to recover fairly rapidly after exclusion of livestock grazing (Rucks 1984; Smith 1989). Native herbaceous understories, however, often recover more slowly and continue to be dominated by exotic species for many years (Szaro and Pase 1983; Rucks 1984). Other nonstructural techniques that allow for natural recovery include restoration of appropriate instream flows (National Research Council 1992). In cases where natural processes cannot be fully restored, however, such as on dammed streams where compromises must be made with other water users, there is a need to refine our ecological knowledge so that natural functions can be simulated or approximated. For example, knowledge of appropriate timing and magnitude of flood flows for recruitment of riparian trees becomes critical in defining instream flows (Stromberg *et al.* 1991).

In severely degraded areas, active restoration measures may be necessary to restore abiotic (*e.g.*, channel and bank conditions) and biotic components of the ecosystem (Kondolf 1990). Abiotic restoration techniques include placement of instream structures such as logs or dams (not recommended by all; Elmore and Beschta 1989) or re-introduction of natural dam builders, beavers (Apple 1985). Biotic restoration techniques includes the planting of "poles" or of rooted cuttings of cottonwood or willow (Anderson and Ohmart 1985; Reiner and Griggs 1989; Pope *et al.* 1990). These techniques, however, are cost-intensive and have had varying rates of success. Low success rates are often a result of failure to restore natural ecosystem conditions — *e.g.*, low soil salinity, relatively stable water tables, and periodic flooding (Carothers *et al.* 1990; Oldham and Valentine 1990).

Recent restoration efforts have focused on the ecosystem level. In addition to restoring the woody dominants, attempts are now being made to restore the understory flora (Swenson 1988; Oldham and Valentine 1989; Wolden 1993) and the soil biota, which includes spores of the fungi which form symbiotic, ecto-mycorrhizal relationships with the riparian trees, as well as invertebrates and other organisms important to nutrient cycling (Baird 1989). Many animal species naturally colonize restored or newly established habitat (Rea 1983). However, special attempts must be made to tailor riparian restoration programs for animal species that have specific habitat requirements such as a minimum width of the riparian zone (Reiner and Griggs 1989).

Restoration of genetic diversity is more difficult. Cottonwoods and willows display much variability in factors such as dispersal phenology and growth rates. To what extent this genetic or phenotypic diversity is irretrievably lost when populations are reduced to a few individuals is unknown. Restoration of the continuity of riparian corridors would go far in restoring genetic exchange between riparian species which have become genetically isolated as their habitats have become fragmented.

ACKNOWLEDGMENTS

Thanks are due to the Arizona Nature Conservancy for providing the stimulus for this manuscript, and to Duncan Patten, Joe McAuliffe, and an anonymous individual for providing helpful review comments.

LITERATURE CITED

- ANDERSON, B. W., and R. D. OHMART. 1985. Riparian revegetation as a mitigating process in stream and river restoration. Pp. 41-79. In: J. A. Gore (ed.). *The Restoration of Rivers and Streams: Theories and Experience*. Butterworth Publishers, Boston, Massachusetts.
- ANONYMOUS. 1989. *Statewide Comprehensive Outdoor Recreation Plan: Arizona Rivers, Streams and Wetlands study*. Arizona State Parks, Phoenix.

- APPLE, L. L. 1985. Riparian habitat restoration and beavers. United States Forest Service General Technical Report RM-120:489-490.
- ARMOUR, C. L., D. F. DUFF and W. ELMORE. 1991. The effects of livestock grazing on riparian and stream ecosystems. *Fisheries* 16:7-11.
- ASPLUND, K. K., and M. T. GOOCH. 1988. Geomorphology and the distributional ecology of Fremont cottonwood (*Populus fremontii*) in a desert riparian canyon. *Desert Plants* 9:17-27.
- BAIRD, K. 1989. High quality restoration of riparian ecosystems. *Restoration and Management Notes* 7:60-64.
- BAKER, W. L. 1990. Climatic and hydrologic effects on the regeneration of *Populus angustifolia* James along the Animas River, Colorado. *Journal of Biogeography* 17:59-73.
- BEAUMONT, P. 1978. Man's impact on river systems: a world-wide view. *Area* 10:38-41.
- BEIER, P., and R. H. BARRETT. 1987. Beaver habitat use and impact in Truckee River Basin, California USA. *Journal of Wildlife Management* 51:794-799.
- BESSEY, C. E. 1904. The number and weight of cottonwood seeds. *Science* 20:118-119.
- BRADLEY, C. E., and D. G. SMITH. 1984. Meandering channel response to altered flow regime: Milk River, Alberta and Montana. *Water Resources Research* 20:1913-1920.
- BRADLEY, C. E., and D. G. SMITH. 1986. Plains cottonwood recruitment and survival on a prairie meandering river floodplain, Milk River, southern Alberta and northern Montana. *Canadian Journal of Botany* 64:1433-1442.
- BRADY, W., D. PATTON, and J. PAXSON. 1985. The development of Southwestern riparian gallery forests. United States Forest Service General Technical Report RM-120:34-43.
- BRIGGS, P. C. 1976. Arizona's groundwater resources supplies and problems. Arizona Water Commission Watershed Symposium Report 8:11-21.
- BRIGGS, M. K. 1993. Developing Plans for Improving the Condition of Degraded Riparian Ecosystems: A Guidebook for Resource Managers. The Rincon Institute, Tucson, Arizona.
- BROCK, J. H. 1987. Potential effects of partial water withdrawals from the Verde River on riparian vegetation. Unpublished report to United States Bureau of Reclamation, Phoenix, Arizona.
- BRODE, J. M., and R. B. BURY. 1984. The importance of riparian systems to amphibians and reptiles. Pp. 30-36. In: R. E. Warner and K. M. Hendrix (eds.). *California Riparian Systems: Ecology, Conservation, and Productive Management*. University of California Press, Berkeley.
- BROTHERSON, J. D., S. R. RUSHFORTH, W. E. EVENSON, and C. MORDEN. 1983. Population dynamics and age relationships of eight tree species in Navajo National Monument, Arizona. *Journal of Range Management* 36:250-256.
- BROWN, D. E. 1982. Biotic communities of the American Southwest - United States and Mexico. *Desert Plants* 4:1-342.
- BROWN, T. C., and M. M. FOGEL. 1987. Use of streamflow increases from vegetation management in the Verde River basin. *Water Resources Bulletin* 23:1149-1160.
- BRYAN, K. 1925. Date of channel trenching (arroyo cutting) in the arid southwest. *Science* 62:338-344.
- BRYAN, K. 1928. Change in plant associations by change in ground water level. *Ecology* 9:474-478.
- BUSCH, S. E., N. L. INGRAHAM, and S. S. SMITH. 1992. Water uptake in woody riparian phreatophytes of the Southwestern U.S.: a stable isotope study. *Ecological Applications*: in press.
- BUSCH, D. E., and S. D. SMITH. 1993. Effects of fire on water and salinity relations of riparian woody taxa of the Southwestern U.S. *Oecologia*: in press.
- CAMPBELL, C. J., and W. A. DICK-PEDDIE. 1964. Comparison of phreatophyte communities on the Rio Grande in New Mexico. *Ecology* 45:492-502.
- CAROTHERS, S. W., G. S. MILLS, and R. R. JOHNSON. 1990. The creation and restoration of riparian habitat in southwestern arid and semi-arid regions. Pp. 351-363. In: J. A. Kusler, and M. E. Kentula (eds.). *Wetland Creation and Restoration: the Status of the Science*. Island Press, Washington, D.C.
- CHIEN, N. 1985. Changes in river regime after the construction of upstream reservoirs. *Earth Surface Processes* 10:143-159.
- CLEMENTS, C. 1991. Beavers and riparian systems. *Rangelands* 13:277-279.
- CROUCH, G. L. 1979. Long-term changes in cottonwoods on a grazed and an ungrazed Plains bottomland in Northeastern Colorado. United States Forest Service Research Note RM-370:1-4.
- CULLER, R. C. 1970. Water conservation by removal of phreatophytes. *Transactions of the American Geophysicists Union* 51:684-689.
- DEBANO, L. F., J. J. BREJDA, and J. H. BROCK. 1984. Enhancement of riparian vegetation following shrub control in Arizona chaparral. *Journal of Soil and Water Conservation* 39:317-320.
- DONNELLY, J. R., and J. B. SHANE. 1986. Forest ecosystem responses to artificially induced soil compaction. I. Soil physical properties and tree diameter growth. *Canadian Journal of Forest Research* 16:750-754.

- ELMORE, W., and R. L. BESCHTA. 1989. The fallacy of structures and the fortitude of vegetation. United States Forest Service General Technical Report PSW-110:116-119.
- EVERITT, B. L. 1968. Use of the cottonwood in an investigation of the recent history of a flood plain. *American Journal of Science* 266:417-439.
- EVERITT, B. L. 1980. Ecology of saltcedar - a plea for research. *Environmental Geology* 3:77-84.
- FAY, J. M. 1978. Vegetation and Flora of the Patagonia-Sonoita Creek Sanctuary, Patagonia, Arizona. Unpublished report to Arizona Natural Heritage Program (Arizona Department of Game and Fish), Phoenix.
- FENNER, P., W. W. BRADY, and D. R. PATTON. 1984. Observations on seeds and seedlings of Frémont cottonwood. *Desert Plants* 6:55-58.
- FENNER, P., W. W. BRADY, and D. R. PATTON. 1985. Effects of regulated water flows on regeneration of Fremont cottonwood. *Journal of Range Management* 38:135-138.
- FFOLIOTT, P. F., W. P. CLARY, and F. R. LARSEN. 1976. Observations of beaver activity in an extreme environment. *Southwestern Naturalist* 21:131-133.
- FOWELLS, H. A. 1965. Silvics of forest trees of the United States. United States Forest Service Agricultural Handbook 271:1-762.
- GARY, H. L. 1965. Some site relations in three floodplain communities in central Arizona. *Journal of the Arizona Academy of Science* 3:209-212.
- GATEWOOD, J. S., T. W. ROBINSON, B. R. COLBY, J. D. HEM, and L. C. HALPENNY. 1950. Use of water by bottom-land vegetation in lower Safford Valley, Arizona. U.S. Geological Survey Water-Supply Paper 1103:1-210.
- GLINSKI, R. L. 1977. Regeneration and distribution of sycamore and cottonwood trees along Sonoita Creek, Santa Cruz County, Arizona. United States Forest Service General Technical Report RM-43:116-123.
- GRAF, W. L., S. L. CLARK, M. T. KAMMERER. 1991. Geomorphology of heavy metals in the sediments of Queen Creek, Arizona, U.S.A. *Catena* 18:567.
- GRIMM, N. B., and S. F. FISHER. 1986. Nitrogen limitation potential of Arizona streams and rivers. *Journal of the Arizona-Nevada Academy of Science* 21:31-43.
- GRINNELL, J. 1914. An account of the mammals and birds of the lower Colorado River Valley. University of California Publications in Zoology 12:51-294.
- GROENEVELD, D. P., and T. E. GRIEPENTROG. 1985. Interdependence of groundwater, riparian vegetation, and streambank stability: A case study. United States Forest Service General Technical Report RM-120:44-48.
- HANSON, J. S., G. P. MALANSON, and M. P. ARMSTRONG. 1990. Landscape fragmentation and dispersal in a model of riparian forest dynamics. *Ecological Modelling* 49:277-296.
- HASTINGS, J. R. 1959. Vegetation change and arroyo cutting in Southeastern Arizona. *Journal of the Arizona Academy of Science* 1:60-67.
- HIGGINS, A. 1981. Avian Succession in Burned Riparian Vegetation. M. S. Thesis, Arizona State University, Tempe.
- HORTON, J. S., F. C. MOUNTS, and J. M. KRAFT. 1960. Seed germination and seedling establishment of phreatophyte species. United States Forest Service Rocky Mountain Forest and Range Experiment Station Paper 48:1-17.
- HOWE, W. H., and F. L. KNOPF. 1991. On the imminent decline of Rio Grande cottonwoods in central New Mexico. *The Southwestern Naturalist* 36:218-224.
- HUNTER, W. C., B. W. ANDERSON, and R. D. OHMART. 1987. Avian community structure changes in a mature floodplain forest after extensive flooding. *Journal of Wildlife Management* 51:495-502.
- INGEBO, P. A. 1971. Suppression of channel-side chaparral cover increases stream flow. *Journal of Soil and Water Conservation* 26:79-81.
- IRVINE, J. R., and N. E. WEST. 1979. Riparian tree species distribution and succession along the lower Escalante River, Utah. *Southwestern Naturalist* 24:331-346.
- JACKSON, J., J. T. BALL, and M. R. ROSE. 1990. Assessment of the Salinity Tolerance of Eight Sonoran Desert Riparian Trees and Shrubs. Desert Research Institute, Reno, Nevada.
- JACKSON, W., T. MARTINEZ, P. CUPLIN, W. L. MINCKLEY, B. SHELBY, P. SUMMERS, D. MCGLOTHIN, and B. VAN HAVEREN. 1987. Assessment of Water Conditions and Management Opportunities in Support of Riparian Values: BLM San Pedro River Properties. United States Bureau of Land Management, Denver, Colorado.
- JACKSON, W., and P. SUMMERS. 1988. Assessment of Water Resource Conditions in Support of Instream Flow Water Rights, Bill Williams River, Arizona. United States Bureau of Land Management, Phoenix, Arizona.
- JENKINS, M.E. 1989. Surface and groundwater assessments supporting instream flow protection at the Hassayampa River Preserve, Wickenburg, Arizona. Pp. 307-316. In: W. W. Woessner, and D. F. Potts (eds). Symposium Proceedings on Headwaters Hydrology. Water Resources Association, Bethesda, Maryland.
- JOHNSON, W. C., Jr. 1992. Dams and riparian forests: Case study from the upper Missouri River. *Rivers* 3:229-242.

- JOHNSON, R. R., and S. W. CAROTHERS. 1982. Riparian Habitats and Recreation: Interrelationships and Impacts in the Southwest and Rocky Mountain Region. United States Forest Service Eisenhower Consortium Bulletin 12:1-31.
- JONES, T. T., and B. W. SNYDER. 1984. Potential effects of sewage effluent removal on the lower Salinas River riparian systems. Pp. 495-504. In: R. E. Warner and K. M. Hendrix (eds.). California Riparian Systems: Ecology, Conservation, and Productive Management. University of California Press, Berkeley.
- JUNK, W. J., P. B. BAYLEY, and R. E. SPARKS. 1989. The flood-pulse concept in river-floodplain systems. Canadian Special Publications in Fisheries and Aquatic Sciences 106:110-127.
- KAUFFMAN, J. B., and W. C. KRUEGER. 1984. Livestock impacts on riparian ecosystems and streamside management implications . . . a review. Journal of Range Management 37:430-438.
- KLEMMEDSON, J. O., and A. R. TIEDEMANN. 1986. Long-term effects of mesquite (*Prosopis juliflora*) removal on soil characteristics. II. Nutrient availability. Soil Science Society of America Journal 50:476-480.
- KONDOLF, G. M. 1990. Hydrologic and channel stability considerations in stream habitat restoration. Pp. 214-227. In: J. Berger (ed.). Environmental Restoration: Science and Strategies for Restoring the Earth. Island Press, Washington, D. C.
- KONDOLF, G. M., and E. A. KELLER. 1991. Management of urbanizing watersheds. California Water Resources Center Report 75:27-40.
- LACEY, J. R., P. R. OGDEN, and K. E. FOSTER. 1975. Southern Arizona riparian habitat: Spatial distribution and analysis. University of Arizona Office of Arid Lands Bulletin 8:1-148.
- LEHR, J. H. 1978. A Catalogue of the Flora of Arizona. Desert Botanical Garden, Phoenix.
- LOWRANCE, R., J. FAIL, Jr., O. HENDRICKSON, R. LEONARD Jr., and L. RASMUSSEN. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34:374-377.
- LEOPOLD, L. B. 1951. Vegetation of the southwestern watersheds in the 19th century. Geographical Review 41:295-316.
- MAHONEY, J. M., and S. B. ROOD. 1991. A device for studying the influence of declining water table on poplar growth and survival. Tree Physiology 8:305-314.
- MANNING, R. E. 1979. Impact of recreation on riparian soils and vegetation. Water Resources Bulletin 15:30-43.
- MCBRIDE, J. R., and J. STRAHAN. 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. American Midland Naturalist 112:235-245.
- MCBRIDE, J. R., N. SUGIHARA, and E. NORDBERG. 1988. Growth and survival of three riparian woodland species in relation to simulated water table dynamics. Unpublished report to Pacific Gas and Electric Co., San Ramon, California.
- MCGINLEY, M. A., and T. G. WHITMAN. 1985. Central place foraging by beavers (*Castor canadensis*): A test of foraging predictions and the impact of selective feeding on the growth form of cottonwoods (*Populus fremontii*). Oecologia (Berl.) 66:558-562.
- MCGLOTHIN, D., W. L. JACKSON, and P. SUMMERS. 1988. Ground water, geomorphic processes, and riparian values: San Pedro River, Arizona. In: M. Waterstone and R. J. Burt (eds.). Proceedings of the Symposium on Water Use Data for Water Resources Management. American Water Resources Association, Tucson, Arizona.
- MCNATT, R. M., R. J. HALLOCK, and A. W. ANDERSON. 1980. Riparian habitat and instream flow studies. Lower Verde River: Fort McDowell Reservation, Arizona. United States Fish and Wildlife Service, Albuquerque, New Mexico.
- MCQUEEN, I. S., and R. F. MILLER. 1972. Soil-moisture and energy relationships associated with riparian vegetation near San Carlos, Arizona. United States Geological Survey Professional Paper 655-E:1-51.
- MILLER, R. R. 1961. Man and the changing fish fauna of the American Southwest. Papers of the Michigan Academy of Science, Arts and Letters 66:365-404.
- MINCKLEY, W. L., and J. N. RINNE. 1985. Large woody debris in hot-desert streams: An historical review. Desert Plants 7:142-153.
- MOORE, D. 1989. Opportunities for riparian ecosystem preservation in the Verde River Basin, Arizona. Pp. 351-360. In: W. W. Woessner, and D. F. Potts (eds). Symposium Proceedings on Headwaters Hydrology. American Water Resources Association, Bethesda, Maryland.
- NATIONAL RESEARCH COUNCIL. 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academy Press, Washington, D.C.
- NILSSON, C. 1982. Effects of stream regulation on riparian vegetation. Pp. 93-106. In: A. Lillehammer and S. J. Saltveit (eds.). Regulated Rivers. Columbia University Press, New York.
- NOBLE, M. G. 1979. The origin of *Populus deltoides* and *Salix interior* zones on point bars along the Minnesota River. American Midland Naturalist 102:59-67.
- OHMART, R. D. and B. W. ANDERSON. 1986. Riparian habitat. Pp. 169-200. In: Cooperrider, A. Y., R. J. Boyd, and H. R. Stuart (eds.). Inventory and Monitoring of Wildlife Habitat. United States Bureau of Land Management Service Center, Denver, Colorado.

- OHMART, R. D., B. W. ANDERSON, and W. C. HUNTER. 1988. The ecology of the Lower Colorado River from Davis Dam to the Mexico-United States international boundary: A community profile. United States Fish and Wildlife Service Biological Report 85(7.19):1-296.
- OLDHAM, J. A., and B. E. VALENTINE. 1989. The Crescent bypass: A riparian restoration project on the Kings River (Fresno County). United States Forest Service General Technical Report PSW-110:457-461.
- PARKER, M., F. J. WOOD, B. H. SMITH, and R. G. ELDER. 1985. Erosional downcutting in lower order riparian ecosystems: Have historical changes been caused by the removal of beaver? United States Forest Service General Technical Report RM-120:35-38.
- PETTS, G. E. 1985. Time scales for ecological concern in regulated rivers. Pp. 257-266. In: J. F. Craig, J. B. Kemper (eds.). *Regulated Streams: Advances in Ecology*. Plenum Press, New York.
- POPE, D. P. 1984. *Methods of Vegetative Regeneration and Moisture Requirements of Selected Southwest Riparian Species*. Unpub. M. S. Report, Arizona State University, Tempe.
- POPE, D. P., J. H. BROCK, and R. A. BACKHAUS. 1990. Vegetative propagation of key Southwestern woody riparian species. *Desert Plants* 10:91-95.
- REA, A. M. 1983. *Once a River: Bird Life and Habitat Changes along the Middle Gila*. University of Arizona Press, Tucson.
- REICHENBACHER, F.W. 1984. Ecology and evolution of Southwestern riparian plant communities. *Desert Plants* 6:15-22.
- REILY, P. W., and W. C. JOHNSON. 1982. The effects of altered hydrologic regime on tree growth along the Missouri River in North Dakota. *Canadian Journal of Botany* 60:2410-2423.
- REINER, R., and T. GRIGGS. 1989. The Nature Conservancy undertakes riparian restoration projects in California. *Restoration and Management Notes* 7:3-8.
- RHOADS, B. L., and M. MILLER. 1990. Impact of riverine wetlands construction and operation on stream channel stability: Conceptual framework for geomorphic assessment. *Environmental Management* 14:799-807.
- ROOD, S. B., and 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.
- ROOD, S. B., and S. HEINZE-MILNE. 1989. Abrupt forest decline following river damming in southern Alberta. *Canadian Journal of Botany* 67:1744-1749.
- ROSENBERG, K. V., R. D. OHMART, W. C. HUNTER, and B. W. ANDERSON. 1991. *Birds of the Lower Colorado River Valley*. University of Arizona Press, Tucson.
- ROSGEN, D. L. 1985. A stream classification system. United States Forest Service General Technical Report RM-120:91-95.
- RUCKS, M. G. 1984. Composition and trend of riparian vegetation on five perennial streams in southeastern Arizona. Pp. 97-107. In: R. E. Warner and K. M. Hendrix (eds.). *California Riparian Systems: Ecology, Conservation, and Productive Management*. University of California Press, Berkeley.
- SEDGWICK, J. A., and F. L. KNOPF. 1987. Breeding bird response to cattle grazing of a cottonwood bottomland. *Journal of Wildlife Management* 51:230-237.
- SHANFIELD, A. N. 1984. Alder, cottonwood, and sycamore distribution and regeneration along the Nacimiento River, California. Pp. 196-201. In: R. E. Warner and K. M. Hendrix (eds.). *California Riparian Systems: Ecology, Conservation, and Productive Management*. University of California Press, Berkeley.
- SIEGEL, R. S., and J. H. BROCK. 1990. Germination requirements of key southwestern riparian species. *Desert Plants* 10:3-8.
- SIMMONS, G. L., and P. E. POPE. 1988. Influence of soil water potential and mycorrhizal colonization on root growth of yellow-poplar and sweet gum seedlings grown in compacted soil. *Canadian Journal of Forest Research* 18:1392-1396.
- SMITH, J. J. 1989. Recovery of riparian vegetation on an intermittent stream following removal of cattle. United States Forest Service General Technical Report PSW-110:217-221.
- STAMP, N. E. 1978. Breeding birds of riparian woodland in south-central Arizona. *Condor* 80:64-71.
- STANFORD, J. A., and J. V. WARD. 1988. The hyporheic habitat of river ecosystems. *Nature* 335:64-66.
- STEVENS, L. E., and G. L. WARING. 1988. The effects of recent flooding on riparian plant establishment in Grand Canyon. Pp. 257-270. Anonymous (eds.). *Glen Canyon Environmental Studies Executive Summaries of Technical Reports*. United States Bureau of Reclamation, Salt Lake City, Utah.
- STINE, S., D. GAINES, and P. VORSTER. 1984. Destruction of riparian systems due to water development in the Mono Lake watershed. Pp. 528-533. In: R. E. Warner and K. M. Hendrix (eds.). *California Riparian Systems: Ecology, Conservation, and Productive Management*. University of California Press, Berkeley.
- STROMBERG, J. C. 1993. Dynamics of *Populus fremontii* at the Patagonia-Sonoita Creek Preserve. Unpublished report to The Arizona Nature Conservancy, Tucson.

- STROMBERG, J. C., and D. T. PATTEN. 1989. Early recovery of an eastern Sierra riparian system following forty years of stream diversion. United States Forest Service General Technical Report PSW-110:399-404.
- STROMBERG, J. C., and D. T. PATTEN. 1990. Riparian vegetation instream flow requirements: A case study from a diverted stream in the Eastern Sierra Nevada, California, USA. *Environmental Management* 14:185-194.
- STROMBERG, J. C., and D. T. PATTEN. 1991. Instream flow requirements for cottonwoods at Bishop Creek, Inyo County, California. *Rivers* 2:1-11.
- STROMBERG, J. C., D. T. PATTEN, and B. D. RICHTER. 1991. Flood flows and dynamics of Sonoran riparian forests. *Rivers* 2:221-235.
- STROMBERG, J. C., B. D. RICHTER, D. T. PATTEN, and L. G. WOLDEN. 1993. Response of a Sonoran riparian forest to a 10-year return flood. *Great Basin Naturalist* 53:118-130.
- STROMBERG, J. C., M. R. SOMMERFELD, D. T. PATTEN, J. FRY, C. KRAMER, F. AMALFI, and C. CHRISTIAN. 1993. Release of effluent into the Upper Santa Cruz River, Southern Arizona: Ecological considerations. American Water Resources Association Effluent Symposium, Tucson, Arizona: In press.
- STRONG, P. I. 1982. Beaver-cottonwood interactions and beaver ecology in Big Bend National Park. M. S. Thesis, Oklahoma State University, Stillwater.
- SULLIVAN, M. E. 1991. Heavy metal concentration in riparian vegetation exposed to wastewater effluent. M. S. Thesis, Arizona State University, Tempe.
- SWENSON, E. A. 1988. Progress in understanding how to reestablish native riparian plants in New Mexico. Pp. 144-150. In: K. M. Mutz, D. J. Cooper, M. L. Scott, and L. K. Miller (tech. coords.). *Restoration, Creation, and Management of Wetland and Riparian Ecosystems in the American West*. Society of Wetlands Scientists, Denver, Colorado.
- SWIFT, B. L. 1984. Status of riparian ecosystems in the United States. *Water Resources Bulletin* 20:223-228.
- SZARO, R. C. 1989. Riparian scrubland and community types of Arizona and New Mexico. *Desert Plants* 9(3-4):1-138.
- SZARO, R. C. 1990. Southwestern riparian plant communities: Site characteristics, tree species distributions, and size-class structures. *Forest Ecology and Management* 33/34:315-334.
- SZARO, R. C., and C. P. PASE. 1983. Short-term changes in a cottonwood-ash-willow association on a grazed and an ungrazed portion of Little Ash Creek in central Arizona. *Journal of Range Management* 36:382-386.
- TAYLOR, D. M. 1986. Effects of cattle grazing on passerine birds nesting in riparian habitat. *Journal of Range Management* 39:254-258.
- TELLMAN, B. 1992. Arizona's effluent dominated riparian areas: Issues and opportunities. University of Arizona Water Resources Research Center Issue Paper 12:1-45.
- TURNER, B. 1983. Recreational Impacts on Riparian Vegetation along the Lower Salt River. M. S. Thesis, Arizona State University, Tempe.
- TURNER, R. M. 1974. Quantitative and historical evidence of vegetation changes along the upper Gila River, Arizona. United States Geological Survey Professional Paper 655-H:1-20.
- VITOUSEK, P. M. 1990. Biological invasions and ecosystem processes: Towards an integration of population biology and ecosystem studies. *Oikos* 57:7-13.
- WALTERS, M. A., R. O. TESKEY, and T. M. HINCKLEY. 1980. Impact of water level changes on woody riparian and wetland communities: Mediterranean region, western arid, and semi-arid region. United States Fish and Wildlife Service OBS-78/93:1-47.
- WARREN, D. K., and R. M. TURNER. 1975. Saltcedar (*Tamarix chinensis*) seed production, seedling establishment, and response to inundation. *Journal of the Arizona Academy of Science* 10:135-144.
- WELCH, E. B., and T. LINDELL. 1980. *Ecological Effects of Wastewater*. Cambridge University Press, Cambridge.
- WILLIAMS, G. P., and M. G. WOLMAN. 1984. Downstream effects of dams on alluvial rivers. United States Geological Survey Professional Paper 1286:1-64.
- WOLDEN, L., J. STROMBERG, D. PATTEN, and H. RICHTER. 1990. Understorey restoration in three riparian forest types (Arizona). *Restoration and Management Notes* 8:116-117.
- WOLDEN, L. G. 1993. Hassayampa River Preserve, Wickenburg, Arizona: Flora, vegetation, and understorey restoration. M.S. Thesis, Arizona State University, Tempe.
- ZIMMERMAN, R. L. 1969. Plant ecology of an arid basin, Tres Alamos-Redington area. United States Geological Survey Professional Paper 485-D:1-51.