WETLANDS, Vol. 18, No. 4, December 1998, pp. 658–668

CHRONOLOGY OF THE SPREAD OF TAMARISK IN THE CENTRAL RIO GRANDE

Benjamin L. Everitt
Utah Division of Water Resources
Box 146201
Salt Lake City, Utah, USA 84114-6201

Abstract: Like many dryland rivers of the southwestern United States, the central Rio Grande suffered a collapse of its native cottonwood forests and an expansion of tamarisk (*Tamarix* spp.) in the early 20th century. A paramount example of an opportunistic colonizer, tamarisk occupied land made available by the plow, the bulldozer, and the shrinking of a channel depleted of flow by upstream water development. Changes in both the physical environment and the native vegetation were well underway by the time tamarisk became widespread. There is no evidence that it actively displaced native species nor that it played an active role in changing the hydraulic or morphologic properties of the river. Its present dominance in the Presidio Valley is due to the chance conjunction in 1942 of a large summer flood, a seed source, and declining cotton prices that fostered abandonment of farm fields. The history of tamarisk on the central Rio Grande demonstrates the complex nature of vegetation change. The passive role of tamarisk in landscape change holds the hope that its response to geomorphic and hydrographic variables can be understood and predicted.

Key Words: tamarisk, vegetation change, water development

INTRODUCTION

In the early 20th century, the introduced tamarisk (*Tamarix spp.*) became naturalized and spread rapidly along many rivers of the southwestern United States (Robinson 1965). Because its spread coincided with large-scale water development and episodes of channel narrowing, its role in the processes of landscape evolution was sometimes confused in the literature, where it was often assigned a more active part than it actually played. It has been blamed for such bad habits as constricting channels (Graf 1982) and increasing flood heights (Burkham 1976, p.1, citing Robinson 1965). Because its spread often coincided with the disappearance of native plant communities, it has sometimes been assigned the role of an aggressive invader actively displacing native species.

On the central Rio Grande, large-scale water development and flow regulation, with consequent channel shrinking as well as clearing of land for agriculture, occurred a decade before the spread of tamarisk, and therefore the cause-and-effect relationships among the variables of hydrology, channel change, and vegetation change are more easily identified than on many other rivers.

The data presented here are derived from my work with the International Boundary and Water Commission (IBWC) in the 1970s and with the El Paso Centennial Museum (Everitt 1977) and the Texas Natural Area Survey (Everitt 1976).

STUDY AREA

The snowfed Rio Grande flows southward from the southern Rocky Mountains in Colorado into the Chihuahuan Desert, a region dominated by summer precipitation. What I call the central Rio Grande is that approximately 560-km reach between Elephant Butte Dam in southern New Mexico and the Confluence of the Rio Conchos, the first significant perennial tributary below Elephant Butte, which joins the Rio Grande at Presidio, Texas (Figure 1). It is essentially what Rubin de Zelis (1751) called "Rio Avajo de el Norte," the lower end of the northern snowfed branch of the river system. The following discussion relates to the Mesilla Valley between Las Cruces, New Mexico and El Paso, Texas; the El Paso Valley between El Paso and Fort Quitman, Texas; and the upper Presidio Valley lying between Candelaria and Presidio, Texas (Figure 1).

TAXONOMY, SEMANTICS, AND PLANT BEHAVIOR

Baum (1967) listed three species of the deciduous pentamerous tamarisk (or saltcedar) as common or nat-

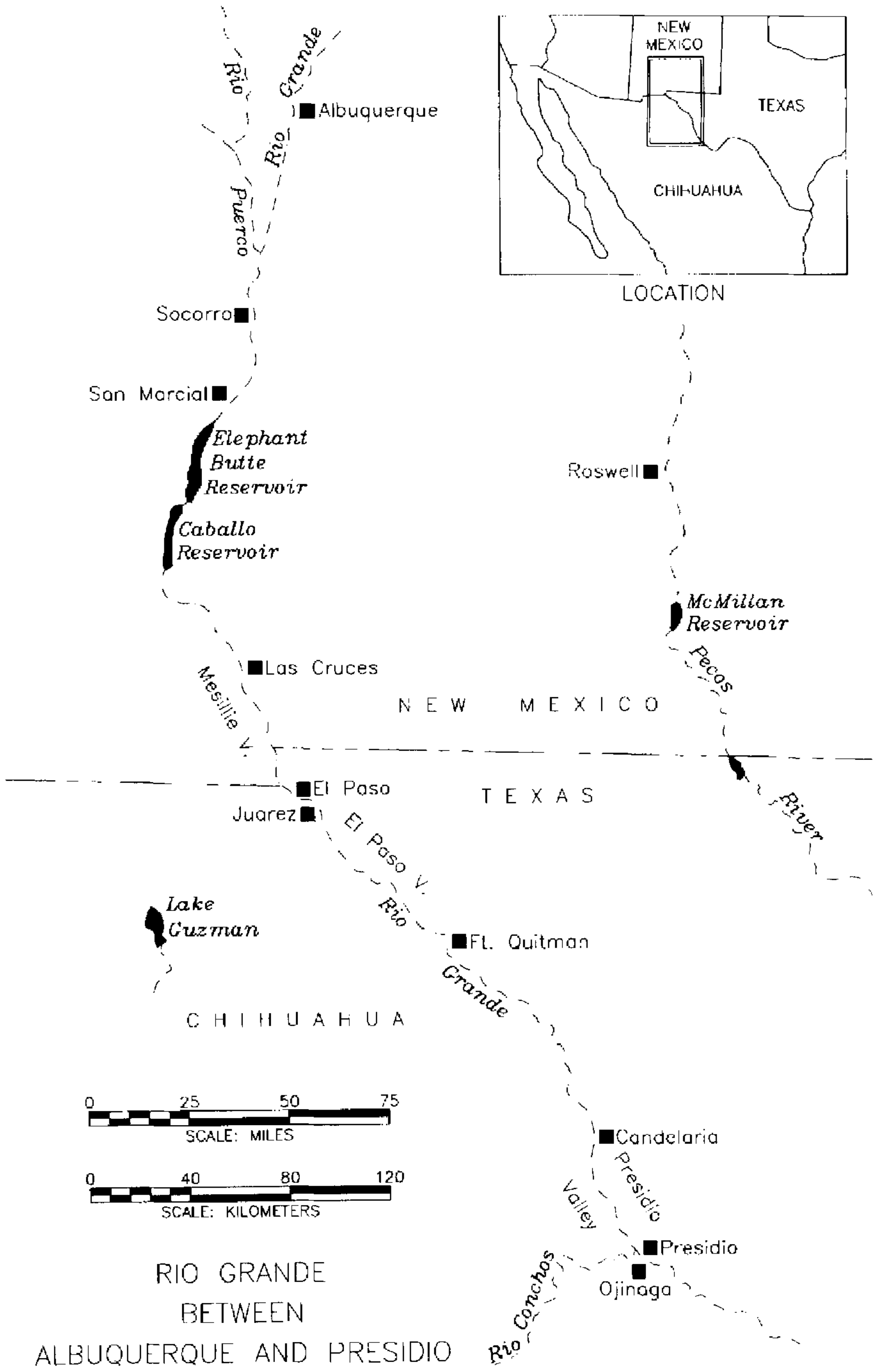

Figure 1. Location map of the Rio Grande between Albuquerque, New Mexico and Presidio, Texas.

uralized in the southwestern United States: *T. Gallica* (L.), *T. chinensis* (Lour.), and *T. ramosissima* (Ledeb.). After a taxonomic study of live specimens collected in the southwest and grown under controlled conditions, Horton and Campbell (1974) concluded that the variations are not sufficiently constant to warrant species differentiation and proposed assigning all to *T. chinensis*. Awaiting further taxonomic definition, recent workers (Brock 1994) have referred all the southwestern U.S. deciduous tamarisks to *Tamarix spp.*

Tamarisk is often classified as "invasive" (Brock 1994). Because the term "invade" is sometimes interpreted as implying aggressive tendencies, I use the term "spread" to denote its increase of range. Many studies, including the present one, have shown that tamarisk is a paramount opportunistic colonizer. Its

Table 1. Greatest monthly discharge and months of zero discharge, Rio Grande above Rio Conchos near Presidio.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1889						93						0000
1890					275							
1891					420							
1892					310					0000	0000	
1893			0000		180							
1894					52							
1895					250							
1896			0000				53					
1897			0000			375						
1898							136			0000	0000	
1899							47					
1900				0000		57					0000	0000
1901	0000	0000	0000	0000	53							
1902			0000	0000	0000		43					
1903	0000	0000					206				0000	0000
1904	0000	0000	0000	0000	0000					258		
1905						745						
1906						285						
1907						395						
1908					104					0000	0000	
1909						189						
1910					275			0000		0000	0000	0000
1911	0000						360					
1912						527						
1913					59							
1914						241						
1915								77				
1916								49				
1917								96				
1918								49				
1919									81			
1920								97				
1921								88				
1922								54				
1923								102				
1924							91					
1925								91				
1926							81					
1927									56			
1928								93				
1929								78				
1930										54		
1931								38				
1932										75		
1933									41			
1934		20								0000	0000	
1935				0000	0000				84			
1936									81			
1937									48			
1938							79					
1939								35				
1940								39				
1941										12		
1942					296							
1943							52					
1944								49				
1945										69		
1946										48		
1947	19											

Table 1. Continued.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1948												7
1949									43			
1950					0000		31					
1951									7		0000	0000
1952	0000	0000	0000				12		0000	0000	0000	0000
1953	0000	0000	0000	0000	0000		6				0000	0000
1954	0000	0000	0000					30				0000
1955		0000	0000		0000					14		0

123 Number is monthly discharge of the greatest month during the calendar year in millions of cubic meters.
0000 Months with no measurable discharge.
Source: IBWC 1956.

short time to seed and production of abundant small seeds easily distributed by wind and water suit it well in the race to occupy new land but do not favor competition with other species.

HISTORY

Beginning with the chronicle of the expedition of Antonio de Espejo in the winter of 1582–1583 (Luxan 1583), three centuries of narrative accounts showed the Rio Grande bordered by dense thickets of brush in many areas and groves of cottonwoods in others, particularly in the El Paso and Presidio Valleys (Everitt 1976). There were oxbow lakes and large swamps and salinas (salt pans) in closed depressions behind natural levees, harboring waterfowl and fish. Rubin de Zelis (1751) provides the first list of the woody riparian vegetation that we can identify with the modern plants: alamos (*Populus wislizenii* Torr.), sauces (*Salix spp*), mesquite (*Prosopis glandulosa* Torr.), tornillo (*Prosopis pubescens* Benth.), and xara (*Baccharis glutinosa* R.& P.).

The riverine environment began to change in the 20th century with large-scale water development. Elephant Butte dam was completed in 1915 in southern New Mexico. This mainstem reservoir, with a capacity 2.5 times the mean annual discharge, completely stored the spring snowmelt flood for a quarter century, from 1915 to 1941. Immediately upon closure of the dam, much of the channel for 560 km downstream began to shrink, decreasing in both width and depth. This was not just encroachment of vegetation on preexisting topography but a "silting in" (Ainsworth and Brown 1933) due to the deposition of sediment scoured from the reach immediately below the dam and delivered by tributaries downstream from the dam, which the regulated river could no longer transport (Lawson 1925, Collier et. al. 1996). Diversion of water at irrigation headgates and sluicing of sediment back to the river exacerbated the process, which included both narrowing and aggradation. Within ten years, the channel at El Paso was so restricted that flood frequency was as great as it had been prior to the construction of Elephant Butte Dam, even though peak flow was only a fraction of its former value (Mueller 1975).

SEASON OF FLOOD AND LOW FLOW

The changing discharge characteristics of the Rio Grande are illustrated by the record of the IBWC gaging station "Rio Grande above Rio Conchos near Presidio" (USGS number 08373500), which has operated nearly continuously since 1900. The record from 1889 to 1900 was developed using the El Paso Gage as a proxy (IBWC 1956). It is 560 km downstream from Elephant Butte Reservoir and 240 km below Fort Quitman, the lower end of the Rio Grande irrigation project. Because the water developed by Elephant Butte storage belongs to the project, the flow reaching Presidio since 1915 consists of irrigation drainage, local storm runoff, and occasionally a "spill" or surplus from upriver.

Inspection of the summary of monthly discharge at Presidio (Table 1) shows that the hydrographic history of the river can be divided into four periods. From 1889 through 1895, the river regularly produced a moderate spring flood in May and was dry infrequently. Between 1896 and 1914, the annual flood moved to June and July and was more erratic in volume and timing. The river was dry more frequently, and such droughts lasted up to seven consecutive months. This change is probably due to a combination of climatic fluctuation and increasing diversions upstream. Except for 1942, the last spring flood (May or June) occurred in 1914, the year before closure of Elephant Butte Dam.

Following flow regulation at Elephant Butte, discharge was more uniformly distributed throughout the year from 1915 to 1933. Peak monthly discharge was

Figure 2. View upstream toward the San Antonio diversion at the upper end of Presidio Valley. Flood-plain vegetation is tamarisk. The river enters from the far right through the tamarisk thicket. Gravel-bedded arroyo enters from the left. Note that, in 1971, the channel occupied only a fraction of the length of the diversion weir. Photo by author, October 1971.

a smaller percentage of total discharge, and there were no months of zero discharge, due to abundant irrigation return flow from the El Paso Valley. Peak discharge occurred most frequently in August due to local storm runoff added to irrigation surpluses.

Beginning in 1934, discharge again became irregular, reflecting the irregularity of local storm runoff, which now became dominant over irrigation return flow. Months with zero discharge reappeared in the record. By the early 1950s, the river remained dry above Presidio for as long as ten consecutive months.

Between October 1941 and September 1942, uncontrolled flow passed Elephant Butte Dam. The annual discharge for 1942 at Presidio of 1.45×10^9 cubic meters was the third largest annual discharge of record (Everitt 1993, Figure 2). Monthly discharge peaked in May of 1942 (Table 1) but was not significantly higher than the discharge of the following four months.

CHANNELIZATION

Because the control of discharge provided by Elephant Butte Dam did not provide flood control, much of the Rio Grande was channelized and leveed in the 1930s and 1940s to improve its efficiency for drainage, delivery of water, and passage of floods (Lawson 1936). In the El Paso valley, 250 km of natural channel was shortened to 140 km and confined within a leveed floodway 180 meters wide (Collier et al. 1996). The channel is maintained by mechanical excavation and the floodway maintained by mowing to prevent the growth of woody vegetation. What few patches of native flood-plain vegetation survived clearing for agricultural development are isolated from the river behind the levees, so their seeds have little chance of falling on fertile riverbank.

CHANNEL SHRINKING

For 240 km downstream from Fort Quitman to Presidio, the river remained in a natural state, except for the regulation and depletion of flow and the construction of a few diversion structures and headgates (Figure 2). The channel shrank in both width and depth in response to the depletion of flow, decreasing its capacity (Everitt 1993). In response to declining capacity, flood frequency at the Presidio gage increased. During the 20 years from 1947 to 1967 (Figure 3), the annual maximum stage steadily increased while annual maximum discharge decreased. After 1966, the river exceeded bankfull every year. The geomorphically driven evolution of hydrographic character undoubtedly had an effect on the propagation, distribution, and

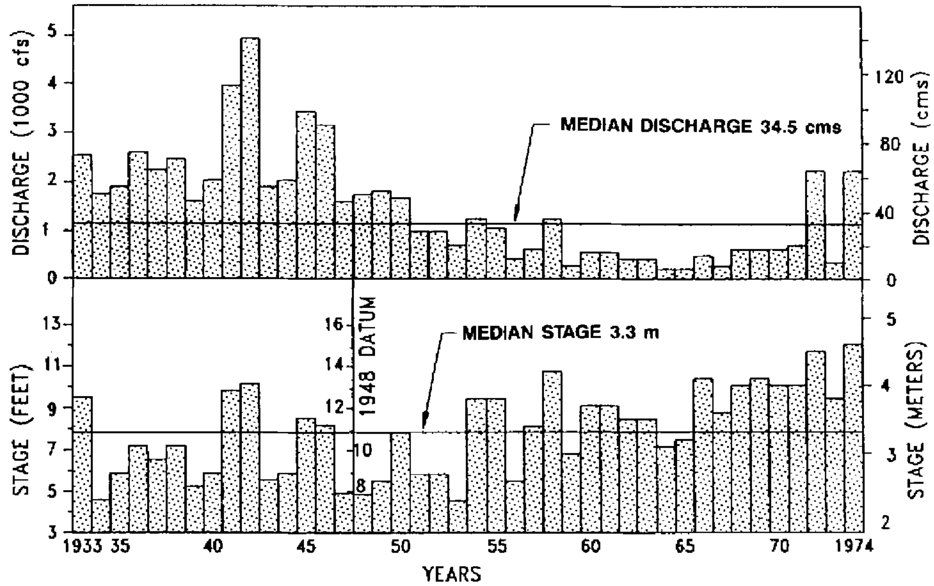

Figure 3. Annual momentary maximum stages and discharges, Rio Grande above Rio Conchos near Presidio, 1933–1974.

survival of riverbank plant species as suggested by Scott et al. (1996) and Graf et al. (1991).

Since vegetation is often used to define channel width, channels may narrow by definition by the encroachment of vegetation without sediment deposition or change in cross-sectional area. Topographic narrowing with loss of cross-sectional area (shrinking) can occur by a combination of accretion of channel-side bars and growth of vegetation (Friedman et al. 1996). Some workers suggest that narrowing is initiated by establishment of vegetation (Schumm and Lichty 1963, Burkham 1972), while some studies show that for some rivers, the deposition that initiated narrowing preceded vegetation establishment (Allred and Schmidt 1997). On the Rio Grande, it is clear that channel narrowing was driven primarily by the deposition of sediment that the depleted flow could no longer carry overbank (Everitt 1993).

Channel aggradation (shallowing) raised dry-season water tables beneath the adjacent flood plain and reduced drainage, favoring development of ephemeral wetlands (Figure 4, and see Collier et al. 1996). After four centuries, the upper Presidio Valley would still be familiar to Antonio de Espejo, who described it (Luxan 1583) as being covered with thickets of brush and containing many pools and swamps. Only the species composition of the vegetation is different, and a smaller river flows in a smaller channel.

AGRICULTURE

Although probably practiced in prehistoric time, historical irrigated agriculture in the El Paso Valley began with the Franciscan mission in 1654 (Sonnichsen 1968, p. 22). The settlement swelled rapidly with the refugees who fled the pueblo revolt of 1680 (Horgan 1954). The head gate of the acequia madre (the main canal) has been in approximately its present location for two centuries. Because of the irregular discharge and lateral instability of the river, however, agriculture developed only slowly until the 20th century. In the Presidio Valley above the Rio Conchos, there is no good evidence of ditch irrigation before 1900.

Agricultural development expanded rapidly after 1915 due to the water supply provided by Elephant Butte Dam, the flood control provided by the dam and subsequent channelization, and the introduction of cotton as a cash crop. In the Presidio Valley, cotton was first harvested in 1913 (Everitt 1977, p. 23). Production in Presidio County peaked in 1928 at 5206 bales, then slowly declined because of decreasing prices, continuing depletion of flow, and increasing flooding (Gregg 1933). The flood of 1942, resulting from a "spill" from Elephant Butte Dam, lasted through the summer, making fields inaccessible and destroying levees, ditches, and headgates. Because of the declining cotton market, agriculture in the Presidio Valley was unable to recover, and most artificially irrigated farmland was abandoned or returned to floodwater pasture. The International Boundary and Water Commission (IBWC 1956) began reporting irrigated land area in 1938. Land irrigated from the river in the Presidio Valley declined from 1312 ha in 1942 to 600 ha in 1944 and to 217 ha in 1956.

Figure 4. Ephemeral marsh in oxbow, bordered by tamarisk thickets. Photo by author, February, 1975.

PRELIMINARY CHRONOLOGY OF THE SPREAD OF TAMARISK

In this setting of dynamic cultural and physical change, the introduced tamarisk appeared and spread downstream along the river and irrigation system. The following preliminary chronology is based on inspection of photographs, notes, and reports incidental to research on other matters and should not be regarded as complete.

1903—Metcalfe (1903) classified the floodplain vegetation of the Mesilla Valley into zones based on distance from and elevation above the river. The primary sandbar pioneer was *Baccharis glutinosa*. Next back from the river was a zone of cottonwood and willow, then tornillo, and finally a zone of cachanillo (*Tessaria sericea* Nutt.). His plant list does not include tamarisk.

1910 Photographs of the Aultman collection in the El Paso public library reveals no tamarisk in floodplain or riverbank vegetation. T.W. Robinson (1965) reported tamarisk in Mesilla Valley in 1910 but gave no details of its habitat or location.

1912—Naturalized tamarisk was first reported in the Pecos River Valley on the delta at the head of McMillan Reservoir in southeastern New Mexico (Harris 1966, p. 420).

1915—Elephant Butte Dam was completed on the Rio Grande in south-central New Mexico, storing the spring snowmelt flood.

1925—Channel shrinking (both narrowing and aggradation) had so reduced the capacity of the Rio Grande channel downstream from Elephant Butte that local runoff overtopped levees and flooded parts of El Paso.

1926 The middle Rio Grande Conservancy District began planting tamarisk along the Rio Puerco, tributary to the Rio Grande above Elephant Butte Reservoir, for erosion control (Everitt 1980). The report by Bryan and Post (1927, p. 52) lists Russian olive (*Eleagnus angustifolia L.*) and *Ailanthus*, but not tamarisk, as naturalizing in the Rio Grande Valley above Elephant Butte.

1926—The first clearly identifiable tamarisk on the riverbank near El Paso appears in a photograph in a Boundary Commission report on bank stabilization. It is a single, young plant about 2 meter in height and at least two years old. Tamarisk may have begun to spread along the river at El Paso in the 1910s or early 1920s but was not yet common in 1926.

1928—Aerial photography of the Presidio Valley shows a channel narrower than that of 1910. Most floodplain was cleared for agriculture up to the 1910 bank. A narrow fringe of brush lined the 1928 channel on bars created by post-1910 narrowing. The species cannot be identified but does not appear to be tamarisk. Photographs of construction of a diversion at Haciendita in the Presidio Valley show cottonwood saplings but no tamarisk.

1929—Photograph of the international bridge between Isleta and Zaragosa in the El Paso Valley, dated

July 24, 1929, shows sparse cottonwoods ranging in height from 1 to 5 meters on a sandy floodplain (IBC 1929). Tamarisk is not evident.

1932—"All along the banks and over the adjacent flood plain (of the Rio Grande in the El Paso Valley) is a heavy growth of willow, salt cedar (tamarisk), and tornillo brush" (Ainsworth and Brown 1933, p. 31). Their "willow" probably includes seepwillow (*Baccharis glutinosa*).

1934—IBWC file photographs of river channelization in the El Paso Valley show mature and flowering tamarisk along irrigation laterals and drains and on some parts of the riverbank. On the flood plain distant from the river are mature cottonwoods and other species. Photos of several steam pumps show that what remained of the native woodland was being fed to the boilers that lifted water from the river.

1935—Tamarisk first appeared on the riverbank at Candelaria in the Presidio Valley (IBWC 1978).

1938—Channelization of the Rio Grande in the El Paso Valley was completed, isolating what remained of the native floodplain woodland behind levees distant from the river. Periodic mowing of the channel bank and floodway was prescribed to prevent the growth of woody vegetation within the levees.

1938—Aerial photographs of the Presidio Valley show a channel narrower than in 1928. The dense fringe of dark brush is likely tamarisk. LeSeur (1945, p. 56) described essentially the same vegetation zonation as Metcalfe (1903), with *Baccharis* the primary sandbar pioneer, but says "*Arundo* and *Tamarix* are well distributed along the Rio Grande, but not on the Conchos."

1942—Oblique aerial photographs of the flood of 1942 show a band of mature and flowering tamarisk along the riverbank in the Presidio Valley, with mature thickets of an unknown species, possibly *Baccharis* or tornillo, back from the river. Here and there are a few old cottonwoods but no sapling thickets, suggesting no surviving cohort within the last decade. The flood covers the entire valley and is apparently carrying the next generation of tamarisk with it (Figure 5).

1967—Aerial photographs of the Presidio Valley show most farmland abandoned and overgrown with tamarisk. Collier et al. (1996) provide several recent oblique aerial photographs.

1972—Photographs of IBWC channel maintenance in the El Paso Valley show that riverbank tamarisk had reached flowering age between periodic mowing of the floodway. In the mower's wake, seed-laden branches float in the river.

Today in the canyons below Fort Quitman and in the Presidio Valley, tamarisk occupies land once covered by cottonwood woodland and tornillo thickets. It has been a part of the landscape of the central Rio Grande for more than a half century. Where it has not been kept in a youthful "thicket" stage by mechanical disturbance or burning, a mature woodland is now appearing, with short trees 10 meters in height and trunks 30 cm in diameter (Everitt 1980).

CONCLUSIONS

The central Rio Grande data support the conclusion of T.W. Robinson (1965, p. 5) that tamarisk (it may not have been the same variety as now dominates) was present possibly as early as 1910 and was being planted for landscaping, windbreaks, and erosion control in the 1920s, but it was not common in the wild until the 1930s. The population explosion of the 1930s came 15 years after large-scale regulation and depletion of flow and 10 years after channel-narrowing was well underway. In the El Paso Valley, it appeared at least as early along the canals, laterals, and drains of the irrigation system as it did on the natural riverbank. Its spread in the El Paso Valley was complicated by river channelization during 1935–1938.

In the Presidio Valley, between 1935 and 1942, tamarisk occupied a narrow fringe of riverbank, new land relicted by the narrowing channel. These initial pioneers had reached maturity by 1942, when the first overbank flood in a decade spread their seeds across the valley to occupy farmland cleared of native vegetation and point bars and oxbows generated by channel migration.

The river in the upper Presidio Valley underwent two separate episodes of narrowing, each accompanied by an increase in the ratio of stage to discharge (Everitt 1993). Between 1910 and 1935, channel width decreased from 100 meters to 30 meters. What few ground-based photos are available show dense thickets of what are probably willow and tornillo. Neither tamarisk nor cottonwood is evident. Again, from 1945 to 1970, the river narrowed from 30 m to 10 m, during a time when tamarisk was one of the primary riverbank colonizers. There is no evidence that the change in the species of riverbank vegetation had an effect on channel width, flood stage, or the process of channel narrowing.

In summary, the spread of tamarisk on the central Rio Grande was opportunistic, driven by a chance coincidence of cultural, economic, and hydrogeomorphic events. It followed different paths on different reaches. There is nothing to suggest that it played an active role in changing the hydraulics or morphology of the river, since changes in both the native vegetation and the physical environment were well underway by the time it became widespread. The central Rio Grande case history demonstrates the complex nature of vegetation change. Because tamarisk is primarily a passive player in the riverine landscape, there is reason to ex-

Figure 5. Rio Grande in flood in the Presidio Valley in the summer of 1942, looking downstream from Candelaria. The discharge is about 127 cms. The riverbank fringe of dark vegetation is tamarisk. A few old cottonwoods dot the flood plain. The river is breaking out of its old channel in several places where land has been cleared to the riverbank and eroding new channels across cultivated fields. Photo by Louis V. Olson for the International Boundary and Water Commission.

pect that the response of riparian vegetation to geomorphic and hydrographic variables can be predicted (Scott et al. 1996) once those relationships are sufficiently well understood.

RECOMMENDATIONS FOR FUTURE STUDY

Although present along the Rio Grande at El Paso by 1925, tamarisk was not abundant until the 1930s after having been planted in headwater tributaries for erosion control. The 1926 Rio Puerco plantings may have been a different species or variety from that which was previously present. DNA typing may permit the mapping of different varieties and an analysis of their provenance.

Studies on other rivers have implicated flow regulation by dams in the demise of the native cottonwood (Mahoney and Rood 1993). The evidence cited here is inconclusive in this regard. A diligent search of the photographic record of the period between the last spring flood (1914) and the appearance of dense stands of tamarisk (1932) might answer this question for the Rio Grande.

In much of the southwest, tamarisk stands have been maintained in a youthful "thicket" stage by burning, chemical treatment, or mechanical disturbance, so that seral species are not able to occupy. Stands that have been allowed to age naturally are rare. An effort should be made to preserve and study some of the "old growth" tamarisk along the Rio Grande, to let it complete its life cycle and provide an understanding of its role in the natural succession of riverbank vegetation. It often takes 40 years for the cottonwood canopy to open and permit colonization of an understory by other woody species. Do tamarisk thickets mature on a similar schedule?

Some of the river between Fort Quitman and Presidio remains unchannelled and un-leveed, or bordered by levees that are ineffective. Here is a natural laboratory in which to observe water consumption and salt cycling in a naturally flooded setting, where the salty leaf-litter of tamarisk is frequently flushed downstream.

LITERATURE CITED

Ainsworth, C.M. and F.P. Brown. 1933. Report on the changes in regimen of the Rio Grande in the valleys below since construction of Elephant Butte Dam, 1917–1932. Report to the International Boundary Commission, El Paso, Texas, USA.

Allred, T.M. and J.C. Schmidt. 1997. Channel narrowing of the Green River near Green River, Utah: History, rates, and processes of narrowing. Geological Society of America. Annual Meeting Program with abstracts.

Baum, B.R. 1967. Introduced and naturalized tamarisks in the United States and Canada. Quarterly Journal Horticultural Taxonomy 15:19–25.

Brock, J.H. 1994. *Tamarix spp.* (Salt Cedar), an invasive exotic woody plant in arid and semi-arid riparian habitats of western U.S.A. Chapter 4. *In* L.C. deWaal, L.E. Child, P.M. Wade, and J.H. Brock. Ecology and Management of Invasive Riverside Plants. John Wiley & Sons, New York, NY, USA.

Bryan, K. and G.M. Post. 1927. Erosion and control of silt on the Rio Puerco, New Mexico. Report to the chief engineer, Middle Rio Grande Conservancy District, Albuquerque, NM, USA.

Burkham, D.E. 1976. Hydraulic effects of changes in bottom-land vegetation on three major floods, Gila River in southeastern Arizona. U.S. Geological Survey Professional Paper 655-J.

Burkham, D.E. 1972. Channel changes of the Gila River at Safford Valley, Arizona, 1846–1970. U.S. Geological Survey Professional Paper 655-G.

Collier, M., R.H. Webb, and J.C. Schmidt. 1996. Dams and Rivers. U.S. Geological Survey Circular 1126.

Everitt, B.L. In press. The Rio Grande. *In* Natural area survey of the Quitman Mountains, Texas. LBJ School of Public Affairs, University of Texas, Austin, TX, USA.

Everitt, B.L. 1977. Historical Background. Chapter V. *In* C.A. Johnson. A preliminary appraisal of cultural and historical resources found along the Rio Grande between Fort Quitman and Haciendita, Texas. University of Texas El Paso Centennial Museum Publication in Anthropology 5:21–25.

Everitt, B.L. 1980. Ecology of salt cedar—a plea for research. Environmental Geology 3:77–84.

Everitt, B.L. 1993. Channel responses to declining flow on the Rio Grande between Fort Quitman and Presidio, Texas. Geomorphology 6:225–242.

Friedman, J.M., W.R. Osterkamp, and W.R. Lewis, Jr. 1996. The role of bed-level fluctuations in the process of channel narrowing. Geomorphology 14:341–351.

Graf, W.L. 1982. Tamarisk and river-channel management. Environmental Management 6:283–296.

Graf, J.B., R.H. Webb, and R. Hereford. 1991. Relation of sediment load and flood-plain formation to climatic variability, Paria River drainage basin, Utah and Arizona. Geological Society of America Bulletin, 103:1405–1415.

Gregg, J.E. 1933. The history of Presidio County. M.S. Thesis. University of Texas, Austin, TX, USA.

Harris, D.R. 1966. Recent plant invasions in the arid and semi-arid southwest of the United States. Annals of the Association of American Geographers: 56:408–422.

Horgan, P. 1954. Great River. Holt Rinehart and Winston, New York, NY, USA.

Horton, J.S. and C.J. Campbell. 1974. Management of phreatophyte and riparian vegetation for maximum multiple-use values. U.S.D.A. Forest Service Research Paper RM-117.

IBC. 1929. International Boundary Commission Minute 113, El Paso, TX, USA.

IBWC. 1956. Flow of the Rio Grande and related Data, 1889–1955. International Boundary and Water Commission, El Paso, TX, USA. Summary Water Bulletin No. 1.

IBWC. 1978. Environmental statement, boundary preservation project. International Boundary and Water Commission, El Paso, TX, USA.

Lawson, L.M. 1925. Effects of Rio Grande storage on river erosion and deposition. Engineering News-record 95:372–374.

Lawson, L.M. 1936. Stabilizing the Rio Grande. Scientific American 155:66–68.

LeSeur, H. 1945. The ecology of the vegetation of Chihuahua, Mexico, north of parallel twenty-eight. University of Texas, Austin, TX, USA. Publication No. 4521.

Luxan, D.P. de. 1583. Expedition into New Mexico made by Antonio de Espejo, 1582–1583. Translated with introduction and notes by George Hammond and Agapito Rey. 1929. The Quivera Society, Los Angeles, CA, USA.

Mahoney, J.M. and S.B. Rood. 1993. A model for assessing the effects of altered river flows on the recruitment of riparian cottonwood. p. 228–232. *In* Riparian Management: common threads and shared interests. USDA Forest Service General Technical Report RM-226.

Metcalfe, O. 1903. The flora of the Mesilla Valley. M.S. Thesis. New Mexico College of Agriculture and Mechanical Arts, Mesilla Park, NM, USA.

Mueller, J.E. 1975. Restless River. Texas Western Press, El Paso, TX, USA.

Robinson, T.W. 1965. Introduction, spread, and aerial extent of saltcedar (*Tamarix*) in the western states. U.S. Geological Survey Professional Paper 491-A.

Scott, M.L., J.M. Friedman, and G.T. Auble. 1996. Fluvial process and the establishment of bottomland trees. Geomorphology 14:327–339.

Schumm, S.A. and R.W. Lichty. 1963. Channel widening and flood plain construction along Cimarron River in southwestern Kansas. U.S. Geological Survey Professional Paper 352-D.

Sonnichsen, C.L. 1968. Pass of the North. Texas Western Press, El Paso, TX, USA.

Zelis, A.V.R. de. 1751. Testimonio de los autos del reconocimiento fecho, Rio Avajo de el Norte, desde el expresado rio hasta las misiones de la junta de dicho-rio, y el Conchos. Archivo General de Indias, Audencia de Guadalajara, 136-Sig. antigua-67-3-30. Transcript on microfilm, El Paso Centennial Museum, University of Texas, El Paso, TX, USA.

Manuscript received 17 February 1998; revision received 11 August 1998; accepted 12 August 1998.