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HYDROLOGIC ALTERATION OF THE LOWER RIO GRANDE TERMINUS: A QUANTITATIVE ASSESSMENT

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ABSTRACT

The lower Rio Grande is one of several imperilled river reaches in North America. Drought and water withdrawals for agriculture and municipal use are acknowledged as primary sources of riverine degradation. We agree that these are critical components adversely affecting the river but also suggest disruption in the normal flood-pulse cycle of the lower Rio Grande, resulting from impoundment of Falcon Lake and poor management of releases from Falcon Lake Dam, have contributed substantially to decline in ecosystem integrity. We provide statistical evidence and real observations in support of the hypothesis that loss of the natural flood-pulse cycle of the lower Rio Grande has detrimentally affected the riparian ecosystem. Although the presence of adverse effects from disruption of the flood-pulse cycle is intuitive, this is the first report quantifying the degree of alteration in the lower Rio Grande. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: Rio Grande; Texas; riparian; alteration; flood-pulse cycle

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INTRODUCTION

Excerpt from CBS Radio Network: 'Title: One of the world's most celebrated rivers is almost gone. There's an old saying in Texas—whiskey is for drinking and water is for fighting. No one's reached for their six-guns yet, but nowhere is the verbal sparring more intense over water than in the lower Rio Grande Valley (LRGV). The reason? That great icon of the old west, the Rio Grande River, is drying up. At best, a bare trickle of river water is all that reaches its natural terminus, the Gulf of Mexico. Further upstream, slower, shallower flow is concentrating pollutants and endangering wildlife. The culprits include a long-term drought, wasteful water practices by agriculture and poor management of available water'. (CBS Radio Network, 2004).

Natural periodic increases and decreases of water levels in large rivers are the foundation of the flood-pulse concept (Junk *et al*., 1989), also referred to as the flood-pulse cycle. In general, it is an extension of the river continuum concept (Vannote *et al*., 1980) except for a more inclusive consideration of the relationship of the river to its associated floodplain. The underlying cornerstone of the flood-pulse cycle is predictability, particularly annual, seasonal fluctuations. The flood-pulse cycle of a river is directly influenced to weather-related events, whether in the form of snowmelt, rainy and dry seasons or general precipitation patterns.

Floods are the fundamental link between aquatic and terrestrial habitats in freshwater ecosystems (Naiman and Decamps, 1997). The flood-pulse cycle represents a major selective pressure driving the evolution of riparian ecosystems because it is generally a reliable, repetitive process occurring over extremely long periods. The flood-pulse cycle also represents a unique selective force because it is driven by disturbance (Pollock *et al*., 1998). Disruption in the form of periodic flooding is the mechanism for ecosystem stability and maintenance of high biodiversity (Bunn and Arthington, 2002). The loss of the flood-pulse cycle leads to lower biodiversity and reduction of natural and recurring successional patterns under which native biota evolved (Richter *et al*., 1998). Cessation or reduction of periodic flooding, or changes in its associated level of intensity, results in a reduction of floral diversity over time and, subsequently, faunal diversity (Blom *et al*., 1990).

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Disruption of the natural flood-pulse cycle in large rivers is frequently the result of anthropogenic activities, most commonly the construction of dams (Cowell and Stoudt, 2002). The rationale for constructing dams and impounding reservoirs is usually generation of hydroelectric power and providing a reliable supply of water for municipal and agricultural use. In addition, flood control initiatives and recreational activities are also enhanced by construction of reservoirs (Poff and Hart, 2002). The effects of these impoundments on the flood-pulse cycle are reduction in flood events, rise and fall rates, zero flow days and variability in annual flow rate fluctuations (Richter and Powell, 1996).

The loss of the natural flood-pulse cycle as a result of dam construction often causes tremendous ecological change (Richter and Richter, 2000). The link between terrestrial and aquatic habitats becomes tenuous and patch dynamics of riparian vegetation are disrupted. Periodic large floods of varying duration drive patch dynamics. In their absence, old, senescing trees are not removed, thus, severely slowing or halting seedling establishment and regeneration of generations. This allows increase in patch size of upland, more arid-adapted species encroaching inward toward the river channel and replacement of more hydrophilic species, which are a crucial aspect of biodiversity. Lateral cutting of the river channel is substantially reduced causing increased vertical cutting and subsequent channelization and loss of sand and gravel bars (Richter and Richter, 2000). The loss of natural rise and fall rates also negatively impacts emergent vegetation by reducing patch size and eliminating them on some stretches. This often facilitates colonization by invasive species. Additionally, by reducing the complexity of riparian patch dynamics, habitat critical for the reproduction of many species, particularly avifauna and ichthyofauna, becomes restricted or eliminated (Richter *et al*., 1997).

The lower Rio Grande is adversely impacted by anthropogenic regulation similar to other North American rivers (Benke and Cushing, 2005). However, despite documentation and acknowledgement of adverse habitat alteration, no quantification of the degree of disruption is available. This is particularly surprising given the lower Rio Grande's status as an international border with Mexico. Also, geopolitical and socioeconomic agendas most certainly have played large roles in the management of this ecologically sensitive drainage. However, successful efforts have been made over the past two decades, particularly by the National Wildlife Refuge System, to purchase riparian land along the Rio Grande for the purpose of habitat restoration. However, without some degree of re-establishment of the pre-impoundment flood-pulse cycle, natural restoration will not occur and artificial restoration attempts, such as facilitated succession, will only be temporary.

Also, the final reach of the lower Rio Grande occurs in an area where subtropical, temperate, desert, shrub steppe and coastal influences converge to form an exceptionally unique ecosystem. Our purpose in preparing this treatise was to demonstrate how a single perturbation (impoundment of Falcon Lake), dramatically influenced this sensitive ecosystem's natural dynamics by markedly altering the biodiversity and biological stability of a once remarkable ecosystem. Further, we contend that degradation of the ecological integrity of this environmentally rich region in this manner renders current restoration efforts impotent in the long term.

Our objectives were to quantify the change in flow regime prior to and after construction of Falcon Lake Dam. Our approach was to compare mean monthly flow rates downstream from Falcon Lake Dam to determine if a linear relationship exists between above and below dam flow rates prior to and following impoundment and the degree of change in linear fit. In addition, we quantified specific areas of change in below dam flow regime (i.e. flood-pulse cycle) using Indicators of Hydrologic Alteration (IHA) software and the Range of Variability approach (Richter *et al*., 1997).

METHODS

Study area

The LRGV of Texas has traditionally referred to a four-county area (Starr, Cameron, Hidalgo and Willacy) at the southernmost tip of Texas comprising about 11,178 km^2 (Jahrsdoerfer and Leslie, 1988). Technically, this area is not a true valley but an extensive delta of the Rio Grande (Figure 1) with a single tributary, the Arroyo Colorado, on the U.S. side. However, the Arroyo Colorado no longer drains into the Rio Grande, but is diverted and empties into the Laguna Madre, Gulf of Mexico about 72 km to the north.

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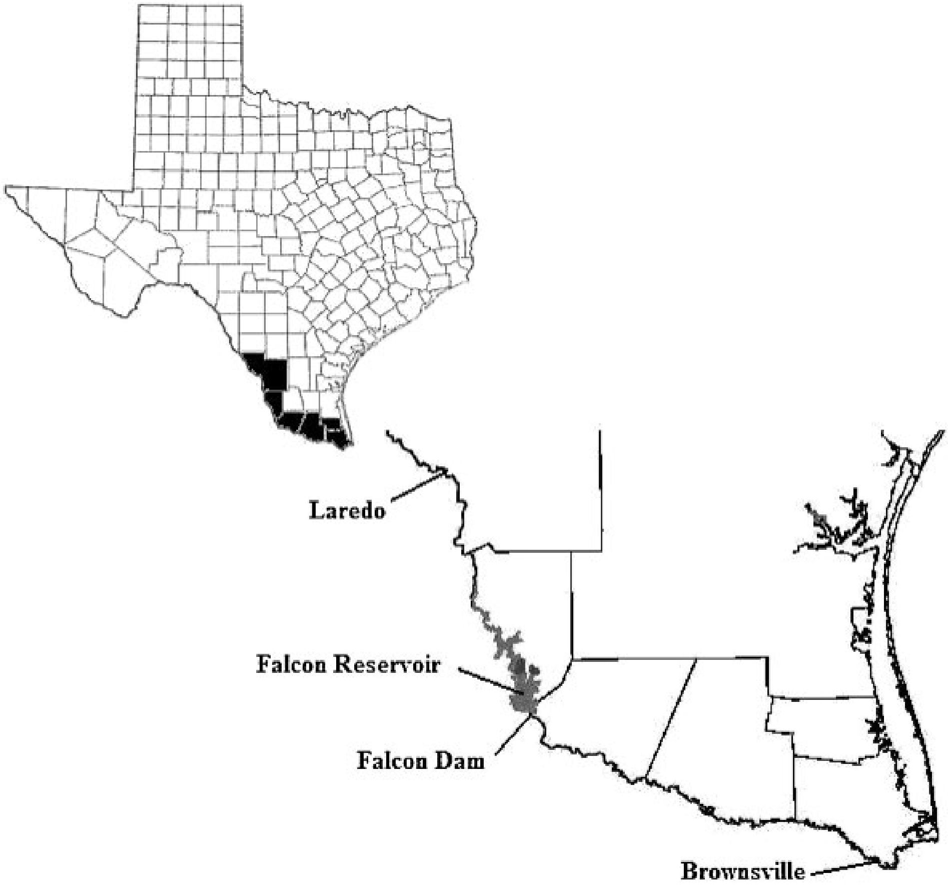

Figure 1. Study area of interest indicating locations of the Laredo and Brownsville gauge stations and Falcon Lake and Dam

The LRGV is included in the Tamaulipan Biotic Province (Blair, 1950), which is composed of several biotic districts and numerous nationally significant biotic communities (USFWS, 1980). Among these biotic communities is the Falcon Woodland (Butterwick and Strong, 1976), ranked fifth in the top 100 nationally significant fish and wildlife areas. This unique ecosystem dominated by Tamaulipan brushland, interdigitates with the riparian zone and is characterized by dense, usually thorny, woodlands of extremely high biodiversity (Jahrsdoerfer and Leslie, 1988), including more than 600 vertebrate species of which more than half are birds.

In riparian zones, vegetation is typically taller with a pre-dominantly closed canopy (Brush and Cantu, 1998). Importantly, riparian zones are not restricted to habitats just along the Rio Grande but also extend onto uplands in narrow strips. These strips have historically provided important refugia for nesting birds as well as corridors for animal movement (Jahrsdoerfer and Leslie, 1988).

Monitoring flow regimes

We used daily flow rate data for the Rio Grande in Texas from the International Boundary and Water Commission (IWBC) to focus on changes in hydrologic regimes before and after impoundment of Falcon Lake. Construction on Falcon Lake Dam began in 1951 with completion in 1954. Our focal point was the IWBC gauge station (08-5750.00) near Brownsville, Texas just upstream from the confluence of the Rio Grande with the Gulf of Mexico. Flow rate at this gauge, because of its location near the mouth of the Rio Grande, is most likely the best indicator of alteration resulting from dam construction and associated (and unassociated) water use along this particular reach of the river.

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Because we were interested in correlating flow regime with construction of Falcon Lake Dam, we used another IWBC gauge station (08-4590.00) just below Laredo, Texas for correlative analysis. This gauge is far enough upstream from Falcon Lake to buffer direct effects of impoundment. Daily flow data at Brownsville were available from 1 January 1934 to present. We used flow data from Laredo for the same time period for comparison. Consequently, flow data from 1934 through 1950 for pre-construction and 1955 through 2004 for post-construction for Laredo and Brownsville were examined. Flow data during the construction period were excluded.

Quantification of change

We used a Student's *t*-test to compare pre- and post-construction flow rate at Brownsville. We compared post- and pre-construction monthly flow means using Pearson's correlation coefficient and analyzed data sets for auto-correlation (Sokal and Rohlf, 1994). We compared correlation slopes of mean monthly flow rates for Laredo and Brownsville before and after construction of Falcon Lake Dam using analysis of variance (ANOVA) (Quinn and Keough, 2002).

We also used IHA software (Smythe Scientific, Boulder, Colorado) to quantify differences in hydrologic regime before and after construction of Falcon Lake Dam. We used IHA 2-period, non-parametric output to calculate 67 statistical parameters based on median values. Of these, 33 were IHA parameters and 34 were environmental flow component (EFC) parameters modelled from characters described by Colwell (1974) and Poff and Ward (1989).

Coefficients of dispersion (CD) were calculated for each parameter using $CD = (75\text{th percentile} - 25\text{th percentile})/(50\text{th percentile})$. In addition, deviation factors were calculated for each parameter using $\text{deviation factor} = |(\text{post-impact value} - \text{pre-impact value})|/(\text{pre-impact value})$. When pre-impact medians = 0, deviation factors could not be calculated.

For this analysis we defined extreme low flow events as the lowest 10% of low flow events, low flow event as median flow minus $\geq$35%, high flow event as median flow plus $\geq$35%, small flood event as a high flow event with a recurrence time of 2 years and large flood event as a high flow event with a recurrence time of 5 years (Table I, Figure 2a). Additionally, we set up the analysis so that a water year was equivalent to calendar year instead of a traditional water year (1 October–30 September).

Table I. Rio Grande flow parameters at Brownsville, Texas pre- and post-construction of Falcon Lake Dam

Parameter	1934–1950	1955–2004
Mean annual flow (m^3/s)	105.30	25.77
Annual CV*	0.61	0.35
Quarterly median flows (m^3/s)		
Quartile 1 (January–March)	35.00	4.20
Quartile 2 (April–June)	68.00	4.80
Quartile 3 (July–September)	100.00	6.00
Quartile 4 (October–December)	61.90	4.80
Daily event frequency (%)		
Extreme low flow	5.20	3.40
Low flow	47.10	86.30
High flow pulse	28.30	10.40
Small flood	14.50	0.00
Large flood	4.90	0.00
Maximum flow by event (m^3/s)		
Extreme low flow	0.20	0.20
Low flow	80.40	80.00
High flow	691.00	459.00
Small flood	796.00	0.00
Large flood	872.00	0.00
Mean zero flow days/year	9.50	2.60

*CV, coefficient of variation.

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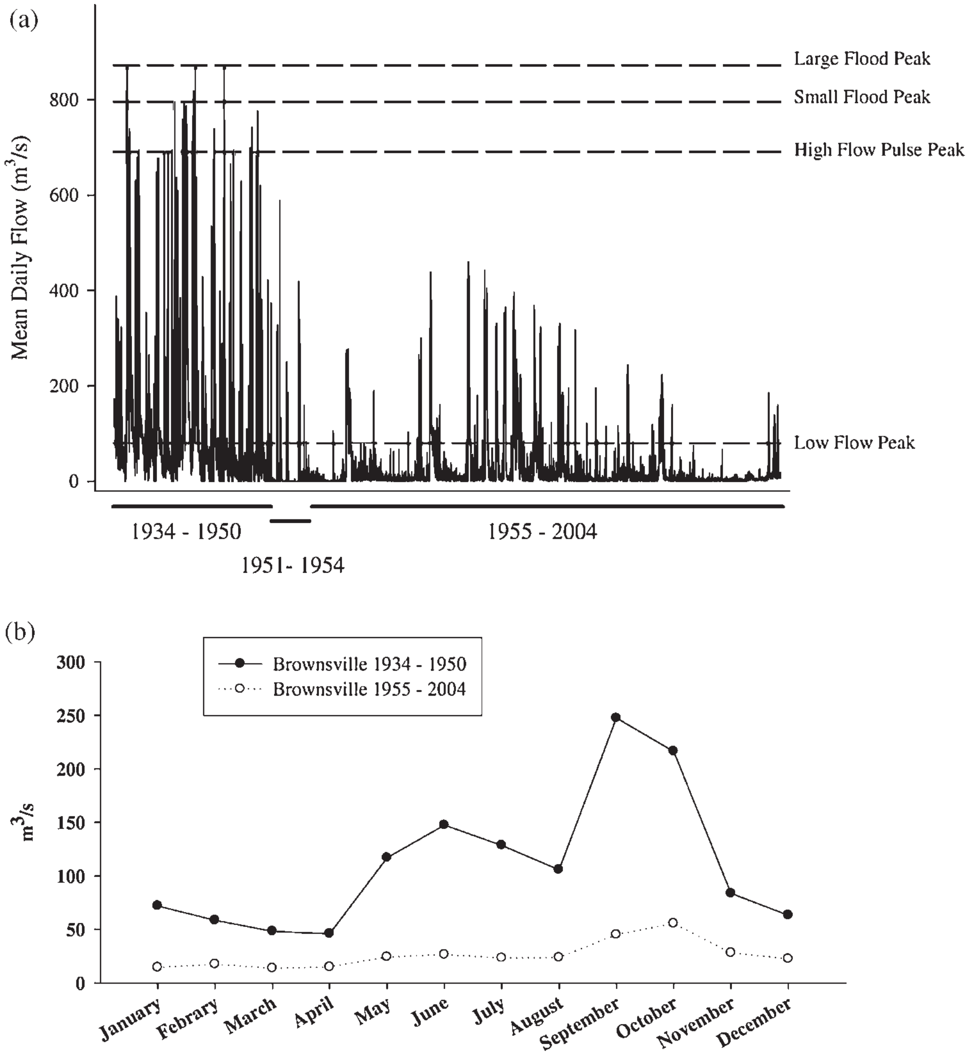

Figure 2. Flow hydrograph (a) and mean monthly flow rates (b) at Brownsville, Texas of the lower Rio Grande before and after construction of Falcon Lake Dam

We used the RVA to compare and evaluate post-impact flow regime using pre-impact flow regime as a reference. We calculated the expected frequency with which post-impact values should fall within the middle 33% of the pre-impact median (median ± 17th percentile). We then calculated an impact factor (IF) for each of the IHA parameters using IF = (observed frequency − expected frequency)/(expected frequency). Positive IF values represented an increase in occurrence of a given event in the post-impact period with no upper bound. Negative IF values represented a decrease in occurrence of a specific event with a lower bound of −1.

RESULTS

Changes in flow regime

Daily, mean monthly (Figure 2b) and mean annual flow rates at Brownsville, Texas were significantly lower following construction of Falcon Lake Dam than prior to construction ($t_{6208} = 40.893$, $p < 0.01$; $t_{11} = 5.467$, $p < 0.01$; $t_{16} = 4.593$, $p < 0.01$, respectively).

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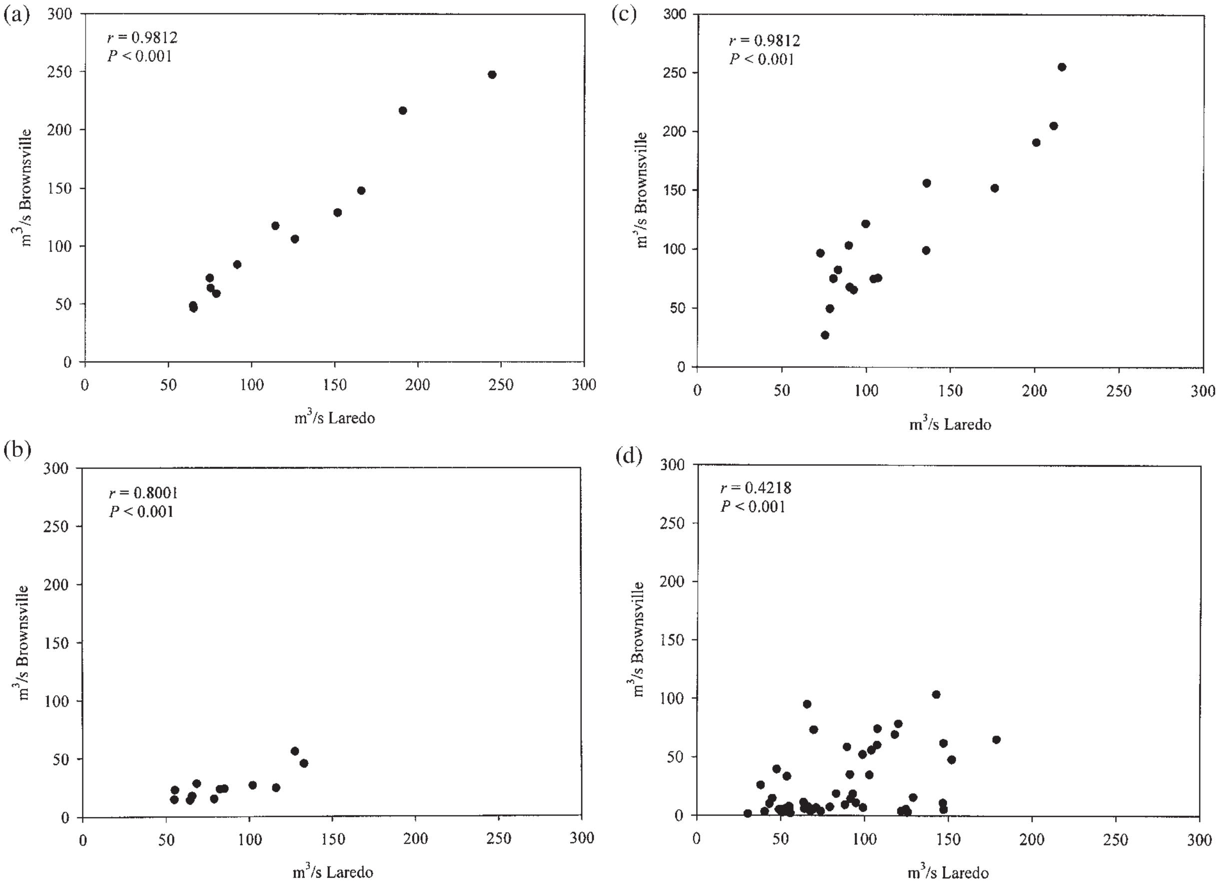

Figure 3. Pre-construction (a) and post-construction (b) correlation of mean monthly flow rates and pre-construction (c) and post-construction (d) correlation of mean annual flow rates of the Rio Grande at Brownsville and Laredo

Correlation of flow rates at Brownsville and Laredo were significant for pre- and post-construction periods, however, degree of correlation was substantially reduced for the post-construction period. Pre- and post-construction correlation of mean monthly flow rates at Brownsville and Laredo were $r = 0.9812$, $p < 0.05$ and $r = 0.8001$, $p < 0.05$, respectively (Figure 3a, b). Pre- and post-construction correlation of mean annual flow rates at Brownsville and Laredo were $r = 0.9156$, $p < 0.05$ and $r = 0.4218$, $p < 0.05$, respectively (Figure 3c, d). Data sets used for pre- and post-construction analysis were not autocorrelated ($\Phi = 0$, $p < 0.01$). Pearson's correlation coefficients were different for pre- and post-construction monthly mean flows for Laredo and Brownsville, $F_1 = 3.72$, $p = 0.06$.

Hydrologic alteration

All but six of the IFs for the 33 IHA parameters were negative. All IFs with positive values related to occasions involving reduced flow: 1-day minimum, 3-day minimum, 7-day minimum, 30-day minimum, number of zero flow days and base flow. Of the 27 parameters, 12 had values of −0.9 or less with four attaining values of −1.0 (Table II).

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Table II. Lower Rio Grande pre- and post-impact range of variation scores for non-parametric middle value categories (CD, coefficient of dispersion)

Parameter	Pre-impact		Post-impact		Impact factor
	Median	CD	Median	CD	
January	2.14	0.75	0.11	1.80	−0.90
February	1.78	0.85	0.15	1.38	−0.90
March	0.85	1.65	0.10	2.55	−0.85
April	0.68	1.56	0.08	1.59	−0.90
May	1.44	2.61	0.18	2.13	−0.71
June	1.86	1.46	0.18	1.59	−0.85
July	2.00	2.06	0.13	1.54	−0.85
August	1.93	1.78	0.10	1.48	−0.76
September	3.41	3.17	0.19	2.52	−0.66
October	3.60	1.58	0.13	8.06	−0.81
November	1.48	1.00	0.18	1.42	−0.95
December	1.33	1.03	0.14	1.75	−0.95
1-day minimum	0.00	0.00	0.01	4.12	0.39
3-day minimum	0.00	0.00	0.01	2.97	0.39
7-day minimum	0.00	211.00	0.02	2.46	0.42
30-day minimum	0.34	1.82	0.06	1.14	0.75
90-day minimum	0.63	1.39	0.10	1.16	−1.00
1-day maximum	19.65	0.38	3.46	1.59	−1.00
3-day maximum	19.06	0.39	3.26	1.66	−1.00
7-day maximum	15.87	0.66	2.89	1.86	−1.00
30-day maximum	8.45	1.22	1.06	4.63	−0.51
90-day maximum	4.91	1.37	0.57	5.42	−0.51
Number of zero days	3.00	5.17	0.00	0.00	0.36
Base flow	0.00	249.30	0.03	3.56	0.05
Date of minimum	137.00	0.33	149.00	0.32	0.03
Date of maximum	180.00	0.28	180.50	0.36	−0.53
Low pulse count	8.00	0.44	5.00	1.60	−0.66
Low pulse duration	5.00	1.80	20.00	3.05	−0.12
High pulse count	7.00	0.57	0.00	0.00	−0.95
High pulse duration	6.00	0.75	12.00	2.44	−0.77
Rise rate	0.14	0.57	0.04	1.49	−0.95
Fall rate	−0.17	−0.58	−0.03	−1.64	−0.95
Number of reversals	97.00	0.13	120.00	0.18	−0.76

DISCUSSION

Ecosystems and their associated communities are composed of structural and functional components (Diamond and Case, 1986). Riparian ecosystems are generally comprised of mesic to semi-mesic floral communities and associated fauna forming a gradient between aquatic and more xeric upland habitats (Knopf *et al*., 1988). Riparian ecosystems have, and continue to be, subject to small- and large-scale manipulations resulting from human water use practices (Carothers and Johnson, 1975). Impoundments, channelization, agricultural diversions and recreational developments represent some of the major perturbations historically imposed on riparian areas (Conine *et al*., 1979; Johnson and Carothers, 1982).

Riparian habitat components

It is widely accepted that undisturbed riparian habitats are among the most diverse terrestrial communities in nature (Malanson, 1993; Naiman *et al*., 1993). Riparian habitat complexity is largely attributable to their dynamic ecological structure formed by the intricate interface between aquatic and terrestrial systems (Naiman *et al*., 1993).

Loss of the natural flood-pulse cycle resulting from construction of Falcon Lake Dam has caused severe alteration of the riparian corridor. This is clearly shown in the IHA and RVA analyses, which indicate severe

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distortion of naturally occurring high and low flow periods in both frequency and duration. Subsequently, land acquisition, as with establishment of the Lower Rio Grande National Wildlife Refuge for the protection of critical habitat, is not sufficient for restoration of habitat. Habitat restoration will be temporary and vegetative composition will eventually return to a state of low diversity even with implementation of facilitated succession without management of water releases resulting in at least partial restoration of the pre-impoundment flood-pulse cycle.

An example of vegetative change associated with loss of the normal flood-pulse cycle on the maintenance and loss of riparian habitat integrity (Junk *et al*., 1989) is Santa Ana National Wildlife Refuge (SANWR) along the Rio Grande, Hidalgo County, Texas. Established in 1943 prior to impoundment of the Rio Grande by its two major reservoirs in Texas (Falcon Lake and Amistad Reservior), SANWR has a mild climate largely influenced by the nearby Gulf of Mexico. Vegetative analysis of the area from 1973 to 1978 (Gelbach, 1987) characterized the site as a closed-canopy subtropical evergreen forest dominated by Texas Ebony (*Pithecellobium ebano*). The floodplain above the riparian woodland was primarily comprised of Rio Grande ash (*Fraxinus berlandieriana*), cedar elm (*Ulmus crassifolia*) and sugar hackberry (*Celtis laevigata*) (Lonard *et al*., 1991).

A comparative study conducted from 1994 to 1996 (Brush and Cantu, 1998) showed a drastic change in the vegetative composition of the site. The riparian zone exhibited a broken canopy, which averaged about 10 m lower in height than in the 1970s. In addition, tree density had increased by about 250%, but trunk diameter had substantially decreased. The most abundant woody vegetation was dead trees with a dense shrub understory. This dramatic change in vegetative composition has been attributed in large part to the construction of Falcon Lake Dam (Gelbach, 1981).

Ichthyofauna

The Rio Grande Delta supported two, relatively distinct fish assemblages before the completion of Falcon Lake (Contreras-Balderas *et al*., 2002). Freshwater fishes ($n = 21$) were most abundant in the section of the river later bound by Falcon Lake, followed by estuarine fishes ($n = 5$) and marine fishes ($n = 3$). Downstream to the river terminus, estuarine ($n = 8$) and marine ($n = 10$) fishes collectively were more abundant than freshwater fishes ($n = 10$).

By the 1980s, anthropogenic impacts related to water diversions and impoundments, habitat modifications and fish introductions were evident. In the section of river downstream from Falcon Lake, nine freshwater fish taxa were introduced and became successfully established. Concurrently, three fishes endemic to the Rio Grande became extirpated. Collectively, the number of estuarine and marine taxa increased to 10. Downstream, the number of marine taxa increased to 26, estuarine taxa increased to 16 and freshwater taxa decreased to five. In general, Rio Grande Delta fishes shifted from an assemblage gradient that consisted of a heterogeneous mix of obligate and facultative riverine fishes upstream and relatively few estuarine and marine fishes downstream, to an assemblage consisting of primarily facultative and introduced fishes upstream with a relatively large and speciose group of estuarine and marine fishes downstream.

Herpetofauna

The role of floods in shaping amphibian and reptilian assemblages has been approached from climatic studies with attention to the effect of mean annual precipitation or other weather factors on species richness (Duellman and Trueb, 1986; Owen, 1989), using simulation models to test the effect of flood frequency on the outcome of interspecific interactions (Doubledee *et al*., 2003). Coinciding reproductive biology with the flood season, and mortality or displacement resulting from massive floods in the drainage systems of rivers have also been evaluated (Ogielska and Konieczny, 1999). With the development of impoundments on the Rio Grande, flooding has become less of a natural disruptive factor on habitats and landscape for amphibians and reptiles.

Fourteen species of amphibians, five aquatic reptiles, 20 lacertilians and 29 serpentes are associated with the environs of the Rio Grande. The reduction in predictable flow patterns has resulted in compositional differences in the herpetofaunal assemblages. Without the natural disruptive occurrence of annual high and low flow regimes, to which these species have co-evolved, the constituency of these assemblages has been altered, with particular species becoming more dominant at the expense of other species. In addition, exotic species have increased and, at least in theory, found an atmosphere conducive for proliferation without the natural checks and balances that effect

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population makeup and interaction. This has left some populations, particularly those at the northern periphery of their range susceptible to serious declines.

Avifauna

More than half of all avian species in the southwestern U.S. are dependent on riparian habitats, whether obligate or facultative (Johnson *et al*., 1977). Riparian ecosystems also provide important habitat for migrating birds, often attracting larger numbers and species of migrants than resident breeders (Hehnke and Stone, 1979). Many environmental pressures affect avian use of specific habitats; however, vegetative structure is a consistent influence (James and Shugart, 1970).

The LRGV is home to about 465 species of breeding birds. However, none of these species are endemic to the LRGV, probably a result of regional topography (see Brush, 2005 for a more in depth assessment). Many species reach the northernmost extent of their range in the LRGV, including red-billed pigeons (*Patagioenas flavirostris*), green parakeets (*Aratinga holochlora*) and brown jays (*Cyanocorax morio*) among other rarities. Yet these species exhibit very different reliance on habitat in the area. Green parakeets first occurred in the LRGV in the 1960s and are currently prolific with large flocks seen throughout the year in urban areas.

Conversely, red-billed pigeons, once numerous in the entire LRGV have declined over the last 25 years to less than 100 individuals in the upstream half of the LRGV inhabiting remnants of mature, dense, riparian vegetation. This is most likely because of the extreme rate of destruction of native habitat historically found in the LRGV and growth of urban areas in the region. In addition, the loss of the natural flood-pulse cycle of this reach of the Rio Grande has negated much of the biodiversity influenced by the confluence of temperate, subtropical, coastal and desert flora unique to this diverse region.

Mammals

The influence of flood-pulse cycles on mammals is not as clear as with other vertebrates. Except for aquatic and semi-aquatic mammals, most mammals near rivers rely on associated riparian zones. Large mammals tend to have a more obtuse use of these zones; whereas, small mammals have a more tangible use. Ecologically the Rio Grande forms an important corridor for the movement of mammals in a vast area changed by agricultural land use. No less than six species listed as threatened or endangered by federal and state agencies occur in habitats associated with the lower Rio Grande.

Additionally, habitats associated with the Rio Grande influence the presence of some 51 mammals. The ephemeral river floodplains and associated riparian zones are a naturally unstable habitat for maintaining small mammal diversity caused by intermediate flooding disturbances. These disturbances alter habitat and landscape structure, thus periodically re-structuring dynamic mammalian populations (Andersen *et al*., 2000). However, impoundments on the river have controlled flood events and removed the flood-pulse cycle and natural annual periods of instability in the riparian zone. As a result, most mammals live in or on the periphery of the riparian zone which is an essential corridor for movement of individuals and subsequent gene flow among isolated populations.

Large mammals through a variety of activities create an array of habitats or patches by modifying the structure (channel morphology, the plant community and biodiversity) and function (productivity, connectivity and resistance) of riparian corridors (Butler, 1995; Johnston, 1995). The lower Rio Grande is unique because of an absence of diversity in large-size herbivores with only a single species, white-tailed deer (*odocoileus virginianus*) present.

Conservation and restoration

The results of our analysis of past and current flow of the lower Rio Grande indicate that the area has been greatly altered by human activity (Figure 4a–d). While we were able to quantify much of the overall change in flow regime in linear terms, it is unlikely that ecosystem dynamics are linearly driven; they are ecologically driven.

The need for and implementation of a comprehensive management plan is intuitive if degradation of this region is to be halted. However, it is also intuitive that certain land practices are going to continue in their current state. Privately owned land will continue to be farmed for maximum production and withdrawal of water to irrigate crops

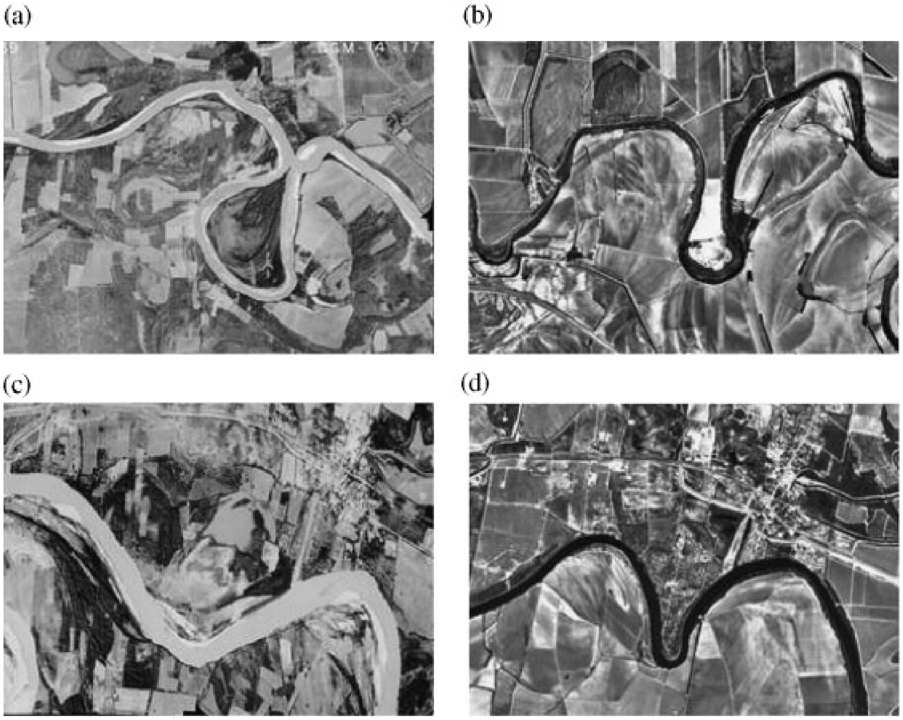

Figure 4. Aerial photographs from 1939 (a, c) and 1995 (b, d) of two areas along the Rio Grande in Hidalgo County, Texas showing changes in geomorphology and riparian habitat loss

and supply municipal demands will persist. Realistically, this poses a difficult management task, particularly because it involves two countries (United States and Mexico), each with different political agendas. However, although formidable, a precedent does exist on an interstate level in the U.S. (Glen Canyon Dam Adaptive Management Program, 2001). Through an international adaptive management program, we suggest some level of ecological restoration could be accomplished.

Other studies have shown that restoring the flow dynamics of a river, even at lower flow rates, are beneficial in recovery of biodiversity (see Richter *et al*., 1997). In addition, we believe restoration of the natural and predictable dynamics (i.e. flood-pulse cycle) of the lower Rio Grande, are critical in re-establishing the connectivity (i.e. correlation) of flow rates between reaches above and below Falcon Lake Dam.

The ultimate objective is the restoration of a diverse and, most importantly, self-sustaining ecosystem. Restoration of some semblance of the natural flood-pulse cycle is imperative to meet this objective. Water quantity is an important component in accomplishing this goal, but ignoring the dynamics of the flow regime with which this ecosystem co-evolved will eventually result in failure. This idea should always be at the forefront of any planning decisions. Any other alternative will simply represent temporary solutions which require continual and repetitive effort over time. An approach we think is ill advised and unfeasible in its short-sighted approach.

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