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An International Borderland of Concern: Conservation of Biodiversity in the Lower Rio Grande Valley

Scientific Investigations Report 2016–5078

U.S. Department of the Interior
U.S. Geological Survey

Front cover. Photographs of *Amazilia yucatanensis* (buff-bellied hummingbird), *Falco femoralis septentrionalis* (northern aplomado falcon), and *Leopardus pardalis albescens* (northern ocelot). Used with permission and modified from ©Larry Ditto Nature Photography.

Back cover. Photograph of *Aythya americana* (redheads). Used with permission and modified from ©Larry Ditto Nature Photography.

Lower banner artwork, Biological Report 88(36), November 1988, U.S. Fish and Wildlife Service.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
meter per second (m/s)	3.281	foot per second (ft/s)
meter per year (m/yr)	3.281	foot per year (ft/yr)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second per square kilometer ($[m^3/s]/km^2$)	91.49	cubic foot per second per square mile ($[ft^3/s]/mi^2$)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)
kilometer per hour (km/h)	0.6214	mile per hour (mi/h)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as

$$°C = (°F - 32) / 1.8.$$

Abbreviations

<	less than
>	greater than
≥	greater than or equal to
CBP	U.S. Customs and Border Protection
CONANP	Comisión Nacional de Áreas Naturales Protegidas
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
GPS	Global Positioning System
Hg	mercury
IBWC	International Boundary and Water Commission
IPM	Integrated Pest Management
IUCN	International Union for the Conservation of Nature and Natural Resources
IVC	International Vegetation Classification
LRGV	Lower Rio Grande Valley
MOU	Memorandum of Understanding
NGO	nongovernmental organization
NWR	national wildlife refuge
PHI	potential hazard index
ppt	parts per thousand
STRC	South Texas Refuge Complex
TPWD	Texas Parks and Wildlife Department
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
vs.	versus
WMA	Wildlife Management Area

Lasaia sula (blue metalmark) ©Larry Ditto Nature Photography

An International Borderland of Concern: Conservation of Biodiversity in the Lower Rio Grande Valley

By David M. Leslie, Jr.

Abstract

The Lower Rio Grande Valley (LRGV) of southern Texas is located on the United States-Mexico borderland and represents a 240-kilometer (150-mile) linear stretch that ends at the Gulf of Mexico. The LRGV represents a unique transition between temperate and tropical conditions and, as such, sustains an exceptionally high diversity of plants and animals—some of them found in few, or no other, places in the United States. Examples include *Leopardus pardalis albescens* (northern ocelot) and *Falco femoralis septentrionalis* (northern aplomado falcon)—both endangered in the United States and emblematic of the LRGV. The U.S. Fish and Wildlife Service (USFWS) manages three national wildlife refuges (Santa Ana, Lower Rio Grande Valley, and Laguna Atascosa) that together make up the South Texas Refuge Complex, which actively conserves biodiversity in about 76,006 hectares (187,815.5 acres) of native riparian and upland habitats in the LRGV. These diminished habitats harbor many rare, threatened, and endangered species. This report updates the widely used 1988 USFWS biological report titled "Tamaulipan Brushland of the Lower Rio Grande Valley of South Texas: Description, Human Impacts, and Management Options" by synthesizing nearly 400 peer-reviewed scientific publications that have resulted from biological and sociological research conducted specifically in the four Texas counties of the LRGV in the past nearly 30 years. This report has three goals: (1) synthesize scientific insights gained since 1988 related to the biology and management of the LRGV and its unique biota, focusing on flora and fauna of greatest conservation concern; (2) update ongoing challenges facing Federal and State agencies and organizations that focus on conservation or key natural resources in the LRGV; and (3) redefine conservation opportunities and land-acquisition strategies that are feasible and appropriate today, given the many new and expanding constraints that challenge conservation activities in the LRGV. The LRGV faces every contemporary conservation challenge of the 21st century, but ongoing human population growth and its associated demands, international border issues, and oil, gas, and alternative energy development dominate impacts that affect conservation in the LRGV. Continued careful syntheses of existing and future information collected in the LRGV are needed on many biological and sociological topics to guide conservation activities. Quick response will no doubt be necessary to face contemporary and difficult-to-predict challenges such as climate change, diminished water availability and quality, spread of invasive species, and habitat loss and fragmentation. Complexities of a guarded international borderland add pressure to small patches of native habitat that remain in many places of the LRGV, particularly along the Rio Grande. Large connected corridors of restored native habitat could be the best option to maintain, and even enhance, the exceptional biodiversity of the LRGV in the face of exceptional human demand.

Introduction

Original Report and Its Impact

In 1988, the U.S. Fish and Wildlife Service (USFWS) published a biological report titled "Tamaulipan Brushland of the Lower Rio Grande Valley of South Texas: Description, Human Impacts, and Management Options" (Jahrsdoerfer and Leslie, 1988). The report synthesized available scientific and managerial information from the Lower Rio Grande Valley (LRGV) as comprehensively as possible given the knowledge base and search capabilities at the time. The report has been widely used and cited more than 120 times in a wide variety of mostly scientific literature. The cumulative number of citations of Jahrsdoerfer and Leslie (1988) through time reflects both continued interest in the LRGV and the value of such syntheses to science and management. The report is out of print, outdated, and in need of revision, but it is available online (http://www.dtic.mil/dtic/tr/fulltext/u2/a322826.pdf, accessed April 28, 2016).

The LRGV was defined as the southernmost counties of Texas (Cameron, Hidalgo, Starr, and Willacy)—a traditional definition used in this update. Jahrsdoerfer and Leslie (1988) provided descriptions and assessments of (1) physiographic, floral, and faunal characteristics of the LRGV; (2) changing human impacts and historical and recent changes in the biota and management of the LRGV; and (3) land-use patterns and managerial approaches to brushland habitats and plant and animal resources. The report included summaries from scientific journals, agency documents, and communications with area experts on pertinent aspects of the LRGV. The stated goal of the report was "to provide a single-source reference of historical review, land-use planning, and management of brushland habitats and wildlife populations in the Lower Rio Grande Valley" (Jahrsdoerfer and Leslie, 1988, p. iii).

Need for Updated Compilation

The USFWS has invested considerable time and resources in the LRGV. It is the only Federal agency with the primary mission of "working with others, to conserve, protect, and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people" (USFWS, n.d.). In extreme southern Texas, this mission is shepherded by the multifaceted activities of the South Texas Refuge Complex (STRC), a collection of three national wildlife refuges (NWRs): Laguna Atascosa, Lower Rio Grande Valley, and Santa Ana (fig. 1). Collectively, STRC encompasses 76,006 hectares (ha) (187,815.5 acres) in Cameron County (44,462 ha), Willacy County (15,455 ha), Hidalgo County (10,590 ha), and Starr County (5,499 ha), representing fee-owned land, conservation easements, and donated land. The STRC protects, conserves, and manages many unique characteristics of the ecologically diverse LRGV, including the federally endangered *Leopardus pardalis albescens* (northern ocelot), *Puma yagouaroundi cacomitli* (Gulf Coast jaguarundi), and *Falco femoralis septentrionalis* (northern aplomado falcon). Nineteen federally threatened or endangered plant and animal species and nearly 60 State-protected species occur in habitats of or surrounding the three NWRs in the STRC.

Santa Ana NWR, established in 1943, is the smallest of the three NWRs at 845 ha (2,087.5 acres). It is located in the Rio Grande flood plain in southern Hidalgo County. The ongoing goal (and challenge) is to conserve dwindling old-growth subtropical riparian forests, resaca (oxbow) wetlands, and associated native brushland for the unique bird community in the LRGV—many species of which are not found anywhere else in the United States. Santa Ana NWR also boasts a high diversity of butterflies that, along with the nearly 400 species of birds recorded there, attracts thousands of nature enthusiasts each year, greatly enhancing the educational mission of the USFWS. At the time of purchase, Santa Ana NWR was an island of native habitat surrounded by thousands of acres of farmland. Since then, and particularly with the establishment of the Lower Rio Grande Valley NWR and subsequent land purchases and restoration, some of the original character of the LRGV has returned.

Lower Rio Grande Valley NWR was established in 1979 to conserve and restore diminishing native habitats in the LRGV. In 1988, it contained 50 tracts totaling 9,817 ha (24,258 acres) in Cameron, Hidalgo, Starr, and Willacy Counties; as of May 2016, it contained 147 tracts totaling 39,035 ha (96,458.4 acres), many of them along the Rio Grande. Its original mission of establishing a continuous riparian corridor along the Rio Grande through land purchase and conservation easements with private landowners has had to adapt to growing pressures from the expanding human population in the LRGV and particularly the recent construction of a segmented and highly patrolled "secure fence" along the United States-Mexico border—segments of which bisect some tracts. Border security issues have caused some traditional USFWS partners, such as Texas Parks and Wildlife Department (TPWD), the Nature Conservancy, and the National Audubon Society, to cease activities on some of their properties near the border along the Rio Grande. These and other challenges have forced the USFWS to rethink its original management strategies for all three NWRs in the STRC. Two inland tracts of the Lower Rio Grande Valley NWR containing saline lakes are designated as a Western Hemisphere Shorebird Reserve Network site and protect about 10 percent of the global population of wintering *Numenius americanus* (long-billed curlews).

Laguna Atascosa NWR is the southernmost waterfowl refuge in the Central Flyway of North America and the second largest of the southern Texas NWRs at about 36,359 ha (89,845.3 acres), having grown from about 19,640 ha (48,532 acres) in the late 1980s (Jahrsdoerfer and Leslie, 1988). It conserves dense tracts of thorn brushland (critical to the northern ocelot and Gulf Coast jaguarundi), coastal prairies, freshwater wetlands, sand dunes, tidal flats, and seagrass meadows associated with the Laguna Madre. Diversity of these habitats results in a commonly heard claim that nearly one-half of all bird species in the United States can be found in Laguna Atascosa NWR at one time or another throughout the year. Wetlands and adjoining uplands are used by migrating and wintering waterfowl, notably *Aythya americana* (redheads), *Grus canadensis* (sandhill cranes), and numerous shorebirds. Laguna Atascosa NWR is designated as part of the Western Hemisphere Shorebird Reserve Network's Laguna Madre site. Federally designated critical habitat of the threatened (in this part of its distribution) *Charadrius melodus* (piping plover) occurs in Laguna Atascosa and Lower Rio Grande Valley NWRs. Laguna Atascosa NWR also is classified as a category V protected landscape/seascape by the International Union for the Conservation of Nature and Natural Resources (IUCN).

Like few other places in the world, the USFWS's STRC and associated areas throughout the LRGV face every contemporary conservation challenge of the 21st century. Since the publication of Jahrsdoerfer and Leslie (1988), significant research has been conducted in the LRGV, in response to the unprecedented changes that have occurred in the area. In some areas, scientific research and resulting publications have been replete, but in many others, they are lacking. There has been no synthesis of the breadth of research that has resulted from these efforts. This report could serve as a road map for Federal and State agencies responsible for conservation of the LRGV to direct focused managerial activities and scientific research related to conservation in areas with the greatest need.

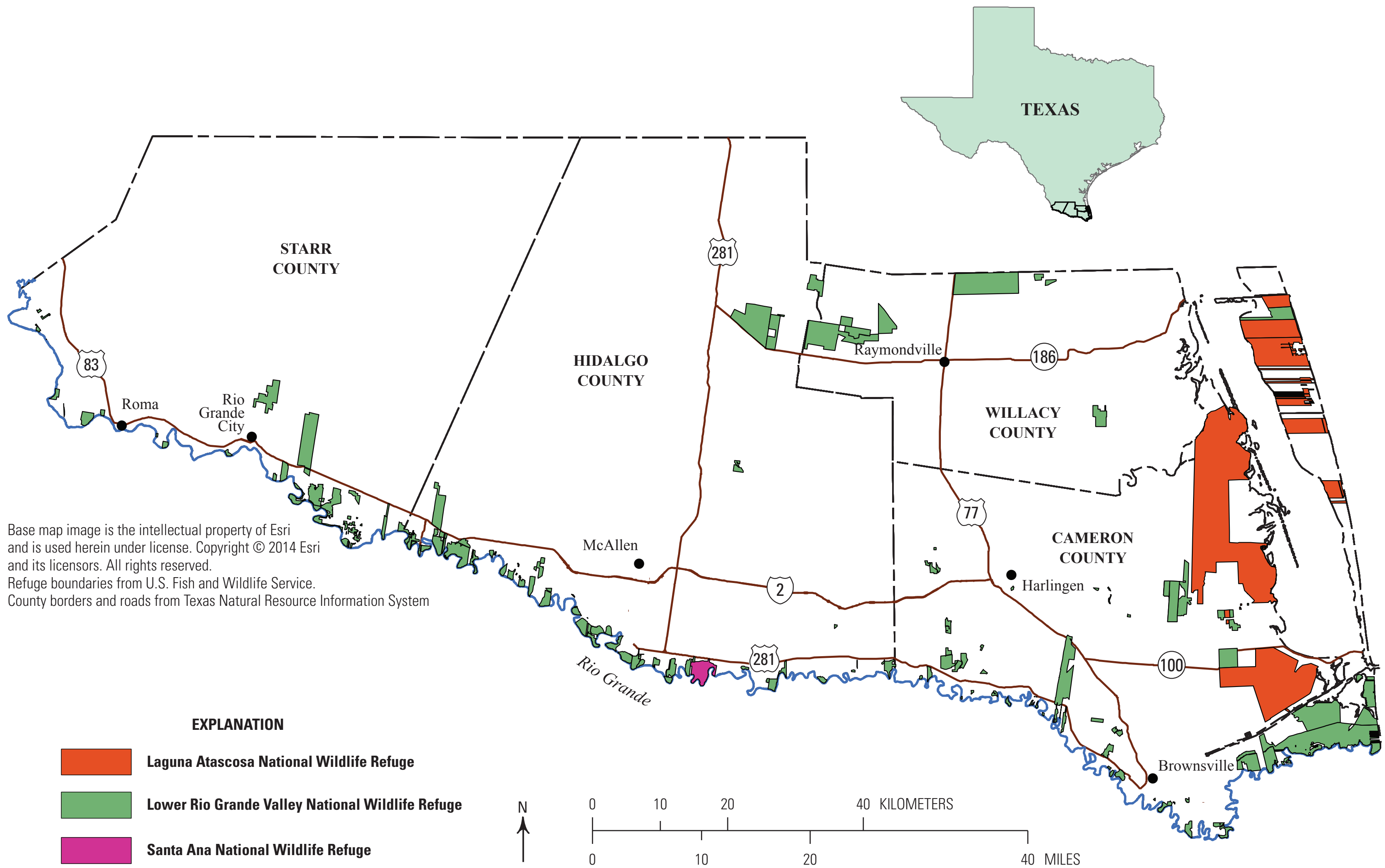

Figure 1. South Texas Refuge Complex, including properties in the Lower Rio Grande Valley National Wildlife Refuge (NWR), Santa Ana NWR, and Laguna Atascosa NWR in Starr, Hidalgo, Willacy, and Cameron Counties in southern Texas.

Survey of LRGV-centric Literature since 1988

While surveying the scientific literature since the publication of Jahrsdoerfer and Leslie (1988), priority was placed on relevant published research mostly in peer-reviewed scientific outlets that was specifically conducted in the four counties of southern Texas (this research hereinafter referred to as "LRGV centric") and synthesizing it relative to contemporary conservation challenges and needs. Research in the LRGV from the late 1980s through 2014 suggests that accomplishments have provided substantial insight in certain areas of conservation need but not in others. During that period, 388 scientific publications were identified with specific research findings from the LRGV (table 1). Collectively, this is an impressive amount of science coming from only four counties, and research topics are highly varied.

It is clear that certain areas, species, and disciplines have received more research than others; for example, birds in general and the northern ocelot in particular received considerably more research attention than other vertebrate categories (table 1). Seven focal areas were apparent across 22 research topics synthesized from the 388 LRGV-centric publications. If all influences that drive research impinged equally on the probability of such research being conducted and published, one would expect about 17 publications per research topic from 1988 through 2014 (table 1). Nevertheless, those seven focal areas accounted for 71 percent of the published papers, highlighting the lack of published work, and presumably research, on many other topics important to conservation of the LRGV.

Aside from the LRGV-centric peer-reviewed literature, numerous stand-alone Federal and State agency reports, at least 66 graduate theses and dissertations, and at least 18 books (12 of them field guides) with relevance to the flora, fauna, and ecology of the LRGV have been published since Jahrsdoerfer and Leslie (1988). A few titles and contributors deserve note because they are comprehensive primers on some of the more important and unique aspects of the LRGV. "Nesting Birds of a Tropical Frontier: the Lower Rio Grande Valley of Texas" by T. Brush (2005) is a thorough summary of the rich diversity of birds and their changing abundance, occurrence, and absence in the LRGV, based on the author's and his students' extensive field research and thorough review of the literature. "The Laguna Madre of Texas and Tamaulipas," edited by J.W. Tunnell, Jr., and F.W. Judd (2002), is a definitive synthesis of 19 contributed chapters on biotic and abiotic characteristics of Laguna Madre in the United States and Mexico. "U.S.–Mexican Borderlands—Facing Tomorrow's Challenges through USGS Science" (Updike and others, 2013) provides a starting point to understand the varied characteristics of the entire 3,152-kilometer (km) border, subdivided into eight subareas of distinct biology, geology, and culture, including the LRGV at its easternmost reach. Great scientific insights from the LRGV also are evident in the collected works of (1) D.J. Shaver and colleagues on sea turtles, particularly the endangered *Lepidochelys kempii* (Kemp's ridley); (2) M. Tewes and his students on the northern ocelot, mostly in and around Laguna Atascosa NWR; and (3) M.A. Mora and colleagues on contaminants in birds, including the northern aplomado falcon, and the northern ocelot.

Report Objectives

This compilation has three goals: (1) synthesize scientific literature published since 1988 related to the biology and management of the LRGV and its unique biota, focusing on communities and plant and animal species of greatest conservation concern and habitat restoration; (2) update challenges facing organizations and agencies that focus on conservation of key natural resources in the LRGV; and (3) redefine a land-acquisition strategy that is feasible and appropriate today, given the many new constraints and conservation challenges facing the LRGV. The report also assesses attainment of conservation goals set forth in Jahrsdoerfer and Leslie (1988) and chronicles changes in conservation challenges and advancement of scientific understanding, specific to the LRGV.

Vegetation removal for agriculture, rangeland management, and urban development and competition for growingly scarce water were cited among the most important conservation challenges facing the LRGV in the late 1980s (Jahrsdoerfer and Leslie, 1988). Although these challenges remain, they are largely overshadowed by the exponential growth of the human population in the LRGV over the past 30 years, which shows no signs of slowing. Additional challenges new to the area include international border issues (that is, increased border-patrol agents and associated infrastructure such as the border fence and related lighting, construction of international bridges, road construction and expansion, and increased disturbance by illegal activities on USFWS property); oil, gas, and alternative energy development projects (e.g., proposed liquefied natural gas facilities and rapidly expanding windfarm development); and even the proposed construction of a rocket launching facility near the mouth of the Rio Grande within one of the largest contiguous tracts in the Lower Rio Grande Valley NWR. These activities impinge on successful conservation of the unique and increasingly isolated and rare natural resources of the LRGV.

Table 1. Numbers of publications focused on the Lower Rio Grande Valley (referred to as "LRGV-centric publications") from 1988 through 2014 (sources: Google Scholar and Web of Science); summary includes publications in peer-reviewed journals, agency series, books and book chapters, and proceedings from scientific meetings but not stand-alone agency reports or graduate theses.

Topic	1988–99	2000–14	Total
Invertebrates (nonpest)			
Total	**8**	**2**	**10**
Vertebrates			
Amphibians and reptiles (including sea turtles)	12	7	19
Fish	5	6	11
Birds	30[a]	44	72
Mammals			
Leopardus pardalis albescens (northern ocelot) specific	17[b]	25	42
Other mammals	6	3	9
Total	**70**	**85**	**155**
Conservation and eco-processes			
General	3	7	10
Habitat restoration and assessment	17	14	31
Plants (including endangered)	3	10	13
Riparian (flooding, sedimentation, etc.)	1	4	5
Seagrass (including brown tide effects)	14	9	23
Soil	0	2	2
Total	**38**	**46**	**84**
Human activities and impact			
Agriculture (pests, irrigation, etc.)	16[a]	22	38
Air quality	1	4	5
Aquaculture (shrimp farming)	2	1	3
Border issues (including the North American Free Trade Agreement)	1	4	5
Climate	0	2	2
Contaminants and pollution	13	11	24
Economic and ecotourism	3	2	5
Exotic and invasive species	6	4	10
Health issues and attitudes	19	15	34
Land use (brush management, grazing)	2	3	5
Waste management	0	3	3
Water use and management	3	2	5
Total	**66**	**71**	**139**
Overall totals	**182**	**204**	**388**

[a]One relevant paper published in 1987 but not cited in Jahrsdoerfer and Leslie (1988) included here.

[b]Two papers published in 1986–87 but not cited in Jahrsdoerfer and Leslie (1988) included here.

Unique Aspects of the Lower Rio Grande Valley

General Description

The LRGV of southern Texas is located in the United States-Mexico borderland and represents a unique transition between the temperate conditions that prevail in most of the United States and the tropics of Mexico and Central America. These conditions give rise to a very diverse mixture of temperate and subtropical species of plants (e.g., Lonard and others, 1991; Donohue, 1992; Lonard, 1993; Lonard and Judd, 1993, 2002; Richardson, 1995; Fulbright and Bryant, 2003; King and Richardson, 2011) and animals (e.g., Gehlbach, 1987; Holt and Lane, 1992; Schmidly, 2004; Brush, 2005) unique in the United States. The LRGV generally lies at the approximate center of the east-west continental gradient of aridity, wetter to the east and drier to the west. Within the LRGV, a gradient occurs from dry conditions in its western reaches to wetter conditions eastward toward the Gulf of Mexico. This gradient exists along a very small linear reach of about 240 km (150 miles [mi]).

Climate of the LRGV is both humid subtropical and semiarid (Thornthwaite, 1948), with very hot summers and mild winters, although cold fronts regularly hit the LRGV each winter, mainly in December–January when the probability of below-freezing temperatures, even severe freezes, is the greatest (e.g., Lonard and Judd, 1991; Cruce Alvarez and Plocheck, 2012). Rainfall is highly erratic, with single rainfall events often making up significant parts of the yearly rainfall (about 53–71 centimeters per year [cm/yr] [21–28 inches per year (in/yr)]) (Cruce Alvarez and Plocheck, 2012), although there are typically wet periods in early summer and late summer/early autumn, with generally drier periods during the rest of the year.

The LRGV is not really a valley but is primarily a delta that slopes gently away from the Rio Grande, with rolling uplands and sandy soils away from the Rio Grande in Starr and northern Hidalgo Counties. The LRGV has been placed into different biotic and vegetative communities by different authors. Clover (1937) was the first to record and classify the unique vegetation of the LRGV consisting of the Chihuahuan Desert and areas with temperate, coastal, and tropical affinities. Blair (1950) placed the LRGV in the Tamaulipan Biotic Province (Judd, 2002) and further defined it as a separate biotic district called the Matamoran District—a designation that is still widely used today. This district was characterized by favorable hydrology and a generally subtropical climate that resulted in luxuriant vegetation, particularly bottomland hardwood species and thicker brush. Today, some maps place the LRGV in the South Texas Brush Country, extending north from the LRGV to the edge of the Edwards Plateau, and the Gulf Coast Prairies and Marshes, extending eastward along the Gulf Coast to Louisiana (Poole and others, 2010); parts of the LRGV have floral characteristics of both.

Floral Characteristics

Classification of plant communities and ecosystems in which they occur varies depending on available data and degrees of refinement, scale, and objectives to meet scientific inquiry and management goals. The 11 biotic communities presented in figure 4 in Jahrsdoerfer and Leslie (1988) were very generalized—descriptively and spatially—and highlighted priority areas for land acquisition by the USFWS in the early stages of the development of the Lower Rio Grande Valley NWR after it was established in 1979. Unfortunately, the 11 biotic communities have been incorrectly cited in the literature as distinct plant associations or communities, which they are not. They were descriptive and intended to highlight the unique biodiversity and habitat variety in the LRGV that could be conserved through land purchases.

Since the late 1980s, the ecoregion concept of Omernik (1987) and Bailey and others (1994) was developed to provide a broad spatial framework to the varied ecosystems (e.g., type, environmental characteristics, etc.) throughout North America, and it expanded quickly and cooperatively with partners from many Federal and State agencies. The ecoregion framework is hierarchical from broad landscape-type classifications in Level I to more refined regional and relatively local classifications in Level IV. In this hierarchical ecoregion framework, the LRGV is described (Omernik and Griffth, 2013) as follows:

Level I	Great Plains
Level II	Texas-Louisiana Coastal Plains
	Tamaulipas-Texas Semiarid Plain
Level III	Western Gulf Coastal Plain
Level IV	*Lower Lower Rio Grande Valley*
	• Lower Rio Grande Alluvial Floodplain
	• Coastal Sand Plain
	• Laguna Madre Barrier Islands and Coastal Marshes
Level IV	*Extreme Upper Lower Rio Grande Valley*
	• Rio Grande Floodplain and Terraces
	• Texas-Tamaulipan Thornscrub

These classifications are descriptive and generally reasonable, but at Level IV, they fail to characterize the great heterogeneity in plant associations/communities that currently exists in the LRGV. This is particularly true in a landscape where 90–95 percent of the once uniform and extensive brushlands or coastal grasslands and about 91–98 percent of the mature riparian woodlands have been negatively affected by or lost to human activities such as water diversions, agriculture, industrialization, and urbanization (e.g., Jahrsdoerfer and Leslie, 1988; Raney and others, 2004; Tremblay and others, 2005).

Approaches to classification of plant communities have changed in the past several decades, particularly with the advent of remote-sensing capabilities, satellite technologies, geographic information system (GIS) software, and resulting open-access online databases. Hathcock and others (2012, 2014) used a standardized approach to delineate six basic physiographic zones in the LRGV (fig. 2) from digital data in the Geologic Atlas of Texas (Texas Natural Resources Information System, 2016), a collaborative effort of the U.S. Geological Survey (USGS) and the Texas Water Development Board in 2002–7. Each physiographic zone was delineated on the basis of geological features resulting, for example, from its underlying geology, soils, and fluvial processes. Hathcock and others (2014) further delineated prominent geological features (initially 1–6 subzones, Hathcock and others, 2012) in 5 of the 6 zones (table 2), refining the great variability in geology and resulting vegetation. The Rio Grande Delta (fig. 2) is the most diverse physiographic zone, containing six prominent geological features and reflecting its riverine and coastal characteristics. This zone also contains the greatest numbers of vertebrate species of concern (n = 18) and invasive plant species of concern (n = 8; table 2); both are discussed in greater detail below.

By using comprehensive and contemporary classifications of global vegetation, Hathcock and others (2012, appendix 1) further characterized the vegetation in the LRGV by using the International Vegetation Classification (IVC; NatureServe, 2013). They identified 38 terrestrial IVC Ecological Communities (that is, plant associations/communities) that occurred within at least 16 higher-level terrestrial IVC Ecological Systems, many of them occurring in more than one of the six physiographic zones. The resulting matrix of vegetation classification and occurrence provides an excellent depiction of the very high degree of overall complexity of the flora in the LRGV (table 3) and the resulting challenges facing ongoing conservation, including restoration. Not all probable Ecological Communities have been identified yet in the IVC system (C. Hathcock, written commun.), but the fact that 20 IVC Ecological Communities are unique in particular physiographic zones (table 4) could provide a useful way to prioritize management activities for restoration and acquisition of rare and unique plant associations and their associated fauna in the LRGV. In particular, 11 of the 38 IVC Ecological Communities identified by Hathcock and others (2012) occur only in the Rio Grande Delta physiographic zone, followed by five unique IVC Ecological Communities in the Bordas Cuesta physiographic zone (table 4).

This recent interpretation and consolidation of the classification of plant communities within physiographic zones in the LRGV could allow the STRC to focus management attention in the zones, subzones, and plant associations with the greatest need of conservation attention (e.g., rarity, habitat restoration, and land acquisition). On the basis of Hathcock and others' synthesis (2012, 2014) of the diversity and complexity of the vegetation in the LRGV and the associated biota (tables 2–4), it would appear that the Rio Grande Delta and, in particular, the Bordas Cuesta are physiographic zones with the greatest future conservation challenges. In particular, the Rio Grande Delta faces extra challenges because human densities and growth are (and have been) greatest within its boundaries. Nevertheless, relative to management and conservation activities, the focus could be on the IVC Ecological Systems and plant associations that currently occur within them. Based on the hierarchy provided in table 3 and including the aquatic Tampaulipan Saline Lake, the following sections highlight unique aspects of those IVC Ecological Systems with the greatest numbers of described plant associations in the six physiographic zones of the LRGV.

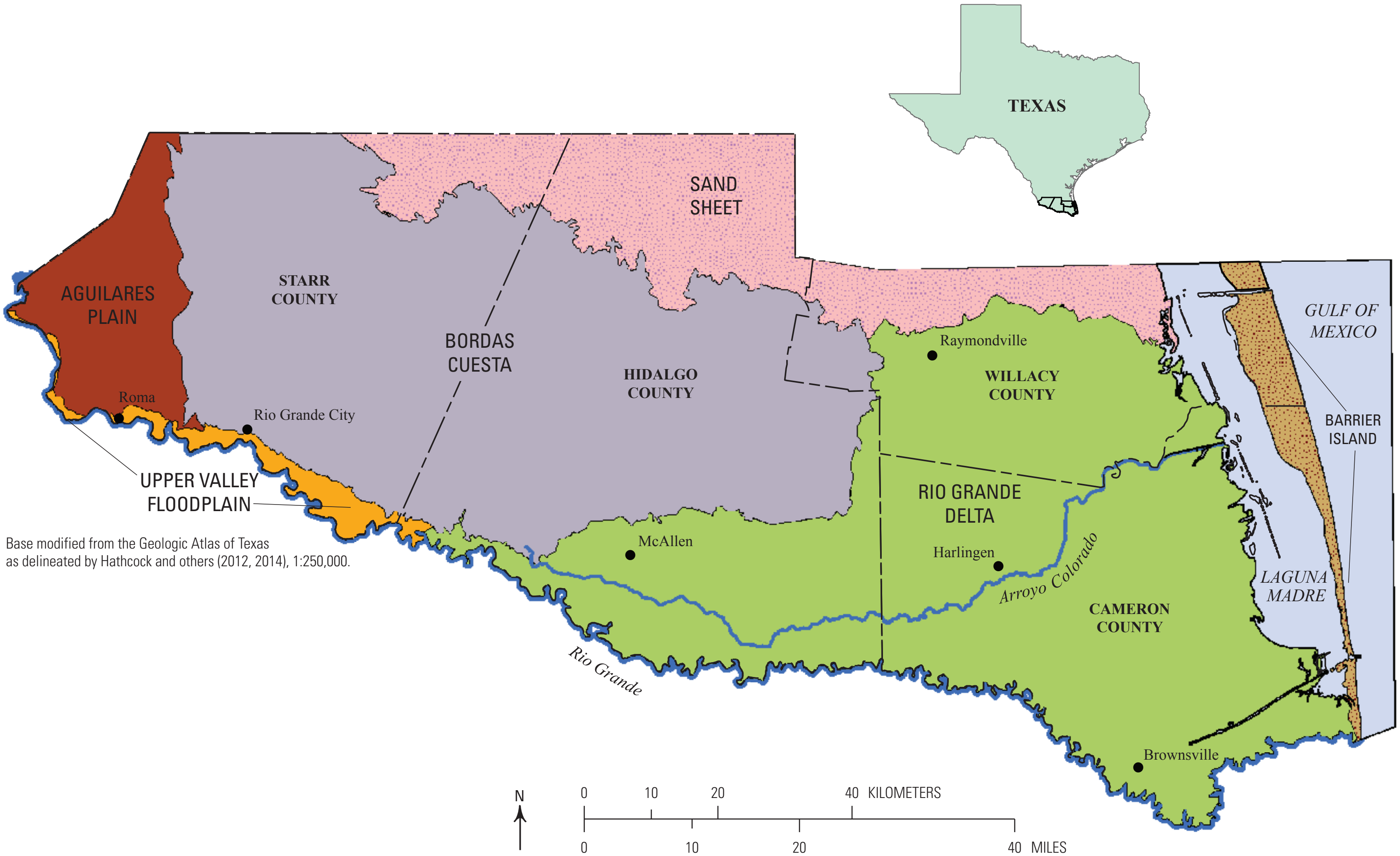

Figure 2. The six major physiographic zones in the Lower Rio Grande Valley (LRGV), uniquely colored as delineated by Hathcock and others (2012, 2014), based on the Geologic Atlas of Texas (Texas Natural Resources Information System, 2016) and historical and geological literature from the LRGV.

Table 2. Physiographic zones, prominent geological features, vertebrate species of concern, and invasive plant species of concern in the Lower Rio Grande Valley, from west (Aguilares Plain) to east (Barrier Island), as outlined in Hathcock and others (2012).

Physiographic zones	Prominent geological features	Primary vertebrate species of concern[a]	Primary plant species of concern[a]	Primary invasive plants of concern
Aguilares Plain	Yegua Formation Laredo Formation	*Polioptila melanura* (black-tailed gnatcatcher)	*Frankenia johnstonii* (Johnston's frankenia) *Physaria thamnophila* (Zapata bladderpod) *Thymophylla tephroleuca* (ashy dogweed)	*Nicotiana glauca* (tree tobacco) *Cenchrus ciliaris* (buffelgrass) *Tamarix ramosissima* (saltcedar)
Upper Valley Floodplain		*Patagioenas flavirostris* (red-billed pigeon) *Psilorhinus morio* (brown jay)		*Arundo donax* (giant reed) *Nicotiana glauca* (tree tobacco) *Tamarix aphylla* (athel tamarisk) *Tamarix ramosissima* (saltcedar)
Bordas Cuesta	Bordas Dip Plain Bordas Breaks Bordas Escarpment	*Coleonyx brevis* (Texas banded gecko) *Phrynosoma cornutum* (Texas horned lizard)[b] *Corvus cryptoleucus* (Chihuahuan raven)[b]	*Asclepias prostrata* (prostrate milkweed) *Astrophytum asterias* (star cactus) *Cardiospermum dissectum* (Chihuahua balloon-vine) *Manfreda longiflora* (Runyon's huaco) *Manihot walkerae* (Walker's manioc)	*Dichanthium annulatum* (Kleberg bluestem) *Cenchrus ciliaris* (buffelgrass)
Sand Sheet	Shallow Water Flats Wind Tidal Flats–Delta	*Gopherus berlandieri* (Texas tortoise)[b] *Glaucidium brasilianum* (ferruginous pygmy-owl)		*Megathyrsus maximus* (guineagrass) *Cenchrus ciliaris* (buffelgrass)

Table 2. Physiographic zones, prominent geological features, vertebrate species of concern, and invasive plant species of concern in the Lower Rio Grande Valley, from west (Aguilares Plain) to east (Barrier Island), as outlined in Hathcock and others (2012).—Continued

Physiographic zones	Prominent geological features	Primary vertebrate species of concern[a]	Primary plant species of concern[a]	Primary invasive plants of concern
Rio Grande Delta	Recent Delta Mission Terrace Beaumont Delta Clay Dunes Shallow Water Flats Wind Tidal Flats–Delta	*Drymobius margaritiferus* (speckled racer) *Drymarchon melanurus erebennus* (Texas indigo snake)[b] *Leptodeira septentrionalis septentrionalis* (northern cat-eyed snake) *Notophthalmus meridionalis* (black-spotted newt) *Siren* sp. (South Texas siren, large Rio Grande form) *Anas fulvigula* (mottled duck) *Buteo nitidus plagiatus* (gray hawk) *Calidris canutus rufa* (rufa red knot) *Camptostoma imberbe* (northern beardless-tyrannulet) *Chondrohierax uncinatus* (hook-billed kite) *Falco femoralis septentrionalis* (northern aplomado falcon)[b] *Icterus cucullatus* (hooded oriole) *Icterus gularis* (Altamira oriole) *Leptotila verreauxi angelica* (white-tipped dove) *Pachyramphus aglaiae* (rose-throated becard) *Lasiurus ega* (southern yellow bat) *Puma yagouaroundi cacomitli* (Gulf Coast jaguarundi)[b] *Leopardus pardalis albescens* (northern ocelot)[b]	*Ambrosia cheiranthifolia* (South Texas ambrosia) *Ayenia limitaris* (Tamaulipan kidneypetal) *Echeandia texensis* (Texas craglily) *Esenbeckia runyonii* (limoncillo)	*Arundo donax* (giant reed) *Dichanthium annulatum* (Kleberg bluestem) *Melia azedarach* (chinaberry) *Megathyrsus maximus* (guineagrass) *Cenchrus ciliaris* (buffelgrass) *Tamarix aphylla* (athel tamarisk) *Tamarix ramosissima* (saltcedar) *Schinus terebinthifolius* (Brazilian pepper)
Barrier Island	Sand Dune and Beach Shallow Water Flats Wind Tidal Flats–Island	*Falco peregrinus* (peregrine falcon)[b] *Lepidochelys kempii* (Kemp's ridley)[b] *Calidris canutus* (red knot) *Charadrius melodus* (piping plover) *Charadrius nivosus* (snowy plover) *Charadrius wilsonia* (Wilson's plover)	*Sporobolus tharpii* (South Padre Island dropseed)	

[a]Species of concern do not necessarily have official State or Federal threatened and (or) endangered designations (see tables 5 and 6), but they have management interest in a particular physiographic zone; these are species
that require more field research to clarify their conservation status or are considered sensitive, rare, or declining by State and Federal agencies or professional and (or) academic scientific societies.

[b]Some of the species occur in more than one physiographic zone.

Table 3. Numbers of terrestrial International Vegetation Classification (IVC) Ecological Communities at the Association Level (known as plant communities), identified by Hathcock and others (2012) in each of their six physiographic zones, tallied for each of the 17 Ecological Systems, as listed on the IVC (NatureServe, 2013), in the Lower Rio Grande Valley.

	IVC Ecological Communities by physiographic zone						
IVC Ecological Systems	**Aguilares Plain**	**Upper Valley Floodplain**	**Bordas Cuesta**	**Sand Sheet**	**Rio Grande Delta**	**Barrier Island**	**Total IVC Ecological Communities**
Tamaulipan Floodplain (22)	3	5	3	3	8		22
Tamaulipan Mixed Deciduous Thornscrub (13)	2		6	2	3		13
Texas Coast Salt and Brackish Tidal Marsh (11)					4	7	11
Tamaulipan Closed Depression Wetland (9)	1	2	2	2	2		9
Tamaulipan Calcareous Thornscrub (5)	2		3				5
Tamaulipan Ramadero (5)	1	1	1	1	1		5
Tamaulipan Savanna Grassland (4)			2	1	1		4
Texas Coast Dune and Coastal Grassland (3)			1	1		1	3
Rio Grande Delta Thorn Woodland (3)					3		3
North American Desert Riparian Mesquite Bosque (3)	1		1	1			3
Central and South Texas Coastal Fringe Forest and Woodland (2)				2			2
Tamaulipan Loma Shrubland and Grassland (2)					2		2
Tamaulipan Saline Thornscrub (2)	1		1				2
Texas Saline Coastal Prairie (2)					1	1	2
Tamaulipan Palm Grove Riparian Forest (1)					1		1
Gulf Coast Chenier Plain Salt and Brackish Tidal Marsh (1)					1		1
Total IVC Ecological Communities represented	**11**	**8**	**20**	**13**	**31**	**9**	
Total IVC Ecological Systems represented	**7**	**3**	**10**	**8**	**11**	**3**	

Table 4. Twenty of the 38 International Vegetation Classification (IVC) Ecological Communities unique to 5 of 6 physiographic zones (see fig. 2), as described by Hathcock and others (2012, 2014) in the Lower Rio Grande Valley.

Physiographic zones[a]	IVC Ecological Community identifier	IVC Ecological Community description
Aguilares Plain	CEGL007760	*Vachellia rigidula – Leucophyllum frutescens – Hechtia glomerata* Shrubland Blackbrush – Cenizo – Guapilla Shrubland
Sand Sheet	CEGL007786	*Prosopis glandulosa* var. *glandulosa – Senegalia greggii – Celtis pallida*/*Paspalum setaceum – Urochloa ciliatissima* Woodland Honey Mesquite – Catclaw Acacia – Spiny Hackberry/Slender Crowngrass – Fringed Signalgrass Woodland
	CEGL007788	*Prosopis glandulosa* var. *glandulosa*/*Colubrina texensis – Monarda fruticulosa – Waltheria indica* Woodland Honey Mesquite/Texan Hogplum – Shrubby Beebalm – Basora-Prieta Woodland
Bordas Cuesta	CEGL002181	*Senegalia berlandieri* South Texas Plains Shrubland Guajillo Shrubland
	CEGL004923	*Helietta parvifolia – Vachellia rigidula – Ebenopsis ebano – Leucophyllum frutescens* Shrubland Barreta Shrubland – Chaparro-Prieto (Blackbrush) – Texas Ebony – Cenizo Shrubland
	CEGL007759	*Vachellia rigidula – Leucophyllum frutescens – Senegalia berlandieri* Shrubland Blackbrush – Cenizo – Guajillo Shrubland
	CEGL007762	*Prosopis glandulosa* var. *glandulosa – Parkinsonia texana* var. *macra* – (*Cordia boissieri*, *Koeberlinia spinosa*) Shrubland Honey Mesquite – Tamaulipan Palo Verde – (Anacahuita, Allthorn) Shrubland
	CEGL007789	*Leucophyllum frutescens – Salvia ballotiflora – Lippia graveolens* Shrubland Cenizo – Shrubby Blue Sage – Mexican Oregano Shrubland
Rio Grande Delta	CEGL002054	*Ebenopsis ebano – Ehretia anacua*/*Condalia hookeri* Forest Texas Ebony – Anacua/Bluewood Forest
	CEGL002056	*Sabal mexicana – Ebenopsis ebano* Forest Rio Grande Palmetto – Texas Ebony Forest
	CEGL002132	*Prosopis glandulosa* var. *glandulosa*/(*Celtis pallida, Phaulothamnus spinescens, Ziziphus obtusifolia* var. *obtusifolia*) Woodland Honey Mesquite/(Spiny Hackberry, Snake Eyes, Lotebush) Woodland
	CEGL002169	*Ebenopsis ebano – Phaulothamnus spinescens* Shrubland Texas Ebony – Snake Eyes Shrubland
	CEGL002170	*Citharexylum berlandieri – Yucca treculeana – Ebenopsis ebano – Phaulothamnus spinescens* Shrubland Berlandier's Fiddlewood – Spanish Dagger – Texas Ebony – Snake Eyes Shrubland[b]

Table 4. Twenty of the 38 International Vegetation Classification (IVC) Ecological Communities unique to 5 of 6 physiographic zones (see fig. 2), as described by Hathcock and others (2012, 2014) in the Lower Rio Grande Valley.—Continued

Physiographic zones[a]	IVC Ecological Community identifier	IVC Ecological Community description
Rio Grande Delta—Continued	CEGL004755	*Spartina patens* – *Schoenoplectus* (*americanus, pungens*) – (*Distichlis spicata*) Herbaceous Vegetation (Marsh) Saltmeadow Cordgrass – (Chairmaker's Bulrush, Common Threesquare – (Inland Seagrass) Herbaceous Vegetation Marsh[b]
	CEGL007752	*Celtis laevigata* – *Ulmus crassifolia* – (*Fraxinus berlandieriana*)/*Rivina humilis* – *Chromolaena odorata* Forest Sugarberry – Cedar Elm – (Mexican Ash)/Pigeonberry – Crucita Forest
	CEGL007764	*Maytenus phyllanthoides* – *Prosopis reptans*/*Spartina patens* Herbaceous Vegetation Gutta-percha Mayten – Creeping Mesquite/Saltmeadow Cordgrass Herbaceous Vegetation[b]
	CEGL007787	*Prosopis glandulosa* var. *glandulosa* – *Celtis pallida*/*Opuntia* spp. – *Neonesomia palmeri* Woodland Honey Mesquite – Spiny Hackberry/Prickly Pear species – Texas Desert Goldenrod Woodland[b]
	CEGL007832	*Prosopis glandulosa* var. *glandulosa*/*Acanthocereus tetragonus* Woodland Honey Mesquite/Triangle Cactus Woodland[b]
	CEGL008456	*Typha domingensis* Tidal Marsh (Herbaceous Vegetation) Southern Cattail Tidal Marsh[b]
Barrier Island	CEGL004971	*Spartina patens* – *Panicum amarum* – *Hydrocotyle bonariensis* Dune Grassland (Herbaceous Vegetation) Saltmeadow Cordgrass – Bitter Panicgrass – Beach Marsh-pennywort Dune Grassland (Herbaceous Vegetation)

[a]The Upper Valley Floodplain physiographic zone does not contain a unique IVC Ecological Community.

[b]Coastal mainland ecological communities unique to the Rio Grande Delta physiographic zone.

IVC Ecological Systems in the LRGV

Tamaulipan Floodplain

The Tamaulipan Floodplain represents the Rio Grande riparian forest ecosystem in the LRGV (fig. 3*A*), which typifies the flood plain (NatureServe, 2013). This Ecological System contains 22 IVC Ecological Communities in 5 of the 6 physiographic zones (table 3), of which 11 only occur in the Rio Grande Delta zone (table 4; Hathcock and others, 2012). Once a lush, continuous, old-growth forest along the lower Rio Grande, the Tamaulipan Floodplain is now fragmented by water manipulations, agricultural practices, and other harmful activities of the past century or more (Jahrsdoerfer and Leslie, 1988). It is typically found along the Rio Grande in Cameron and Hidalgo Counties, and a prime example occurs at Santa Ana NWR (e.g., Lonard and Judd, 2002). Diagnostic characters include occurrence in the lowland flood zone of the Rio Grande, now highly modified; subtropical and tropical vegetation; and forest/woodland landscapes somewhat terraced from true riparian vegetation near the river and bottomland forests to more upland terraces of thorny shrubs. The Tamaulipan Floodplain is a mosaic of resacas, which are old meander channels of the Rio Grande (e.g., oxbows) and old natural levees containing *Parkinsonia aculeata* (retama), *Sesbania drummondii* (rattlebox), and *Mimosa pigra* (black mimosa); riparian areas are represented by *Salix nigra* (black willow); and upland, typically drier terraces of often thorny plants are represented by *Leucophyllum frutescens* (cenizo), *Guaiacum angustifolium* (guayacan), *Ebenopsis ebano* (Texas ebony), and *Sideroxylon celastrinum* (coma). The true bottomland forest can be very conspicuous because of its high stature—up to 15 meters (m) (49 feet [ft])—and contains large *Celtis laevigata* (sugarberry), *Ulmus crassifolia* (cedar elm), *Fraxinus berlandieriana* (Mexican ash), and *Leucaena pulverulenta* (tepeguaje), often covered with epiphytes (e.g., *Tillandsia* spp.) if mature enough. Understory vegetation in this community can be lush and contain various species, but it is completely dependent on the density of the overstory canopy. Fire likely had a limited role in this community because of the usually damp conditions from periodic flooding, which are greatly diminished today (2016).

Figure 3. Vegetative diversity of inland ecological systems in the Lower Rio Grande Valley along the Rio Grande and upslope from it. *A*, Tamaulipan Floodplain. *B*, Tamaulipan Mixed Deciduous Thornscrub upslope from the Rio Grande. *C*, Tamaulipan Calcareous Thornscrub. ©Larry Ditto Nature Photography, used with permission.

Tamaulipan Mixed Deciduous Thornscrub

The Tamaulipan Mixed Deciduous Thornscrub is found primarily in Cameron and Hidalgo Counties, and it contains 13 Ecological Communities in 4 of the 6 physiographic zones (table 3), of which 5 only occur in the Bordas Cuesta zone (table 4; Hathcock and others, 2012). This Ecological System contains highly variable associations of shrublands and woodlands (fig. 3*B*), occurring on a variety of substrates and landforms. A mere 5 percent or less of the original community remains in a natural state in the United States (perhaps more in Mexico—Jiménez Pérez and others, 2013), having been lost primarily to agriculture and expanding industrialization and urbanization. According to the NatureServe classification, this system shares characteristics with and often abuts Tamaulipan Savanna Grasslands and Tamaulipan Saline Thornscrub—differences between them may be very subtle. Diagnostic characters include a tropical xeric character, shrub and (or) low woodland dominance, nearly closed canopy with limited herbaceous layer, occurrence on lowland to upland sites associated with past alluvial processes of the Rio Grande, and clay or clay-loamy soils, sometimes associated with high salinity. The system is typically dominated by *Prosopis glandulosa* var. *glandulosa* (honey mesquite), cenizo, and species of *Acacia* (Eddy and Judd, 2003), with a wide variety of codominant or subdominant shrubs (e.g., *Amyris texana* [Texas torchwood]; *Celtis pallida* [spiny hackberry]; *Karwinskia humboldtiana* [coyotillo]; and *Zanthoxylum fagara* [colima]). *Opuntia engelmannii* var. *lindheimeri* (Texas prickly pear) is often abundant, and the limited herbaceous layer may include *Trichloris pluriflora* (four-flower trichloris) and *Setaria texana* (bristlegrass). Emergent honey mesquite and other tall shrubs may reach 4 m (13 ft) in height, but the entire canopy is most dense at about 2 m (6.6 ft). Lack of fire currently maintains this community (C. Hathcock, written commun.).

Texas Coastal Salt and Brackish Tidal Marsh

The Texas Coastal Salt and Brackish Tidal Marsh is a tidally influenced, marshy Ecological System that occurs on coastal plains of Cameron and Willacy Counties and typically on the lagoon side of barrier islands (fig. 4*E*). It contains 11 Ecological Communities in 2 of the 6 physiographic zones, of which seven communities occur in the Barrier Island zone (table 3). It is a key habitat in Laguna Atascosa NWR (Judd and Lonard, 2002) and the Boca Chica tract of the Lower Rio Grande Valley NWR. Diagnostic characteristics include dominance by tidal grasses; windy tidal and estuarine influences; freshwater input into Laguna Madre; soils ranging from sand, silt, and clay depending on juxtaposition with geomorphic characteristics such as sheltered lagoons and exposed shorelines; and generally 0–2 m (0–6.6 ft) above mean sea level. Plant composition is largely influenced by soil, elevation, and salinity. When salinities are 25–35 parts per thousand (ppt), *Spartina spartinae* (Gulf cordgrass—Cooper and Wagner, 2013) can form monotypic stands, but as salinity increases, open mudflats are characteristic, with sparse coverage of *Salicornia bigelovii* (dwarf glasswort), which can become invasive on disturbed tidal flats (Withers, 2002b; Onuf, 2006). More moderate salinities (10–25 ppt) and higher elevations give rise to dominance by *Spartina patens* (saltmeadow cordgrass). As freshwater input increases around deltas, *Paspalum vaginatum* (seashore paspalum) and *Schoenoplectus americanus* (chairmaker's bulrush) become more common. At the highest elevations of about 2 m (6.6 ft), plant associations become more diverse (Judd and Lonard, 2002) and include *Distichlis spicata* (inland saltgrass), *Distichlis littoralis* (shoregrass), *Sporobolus virginicus* (seashore dropseed), *Borrichia frutescens* (sea-ox-eye daisy), *Rayjacksonia phyllocephala* (camphor daisy), and *Iva angustifolia* (sumpweed). *Avicennia germinans* (black mangrove) is sparsely distributed in some mid-elevation, high-saline marsh zones in the LRGV (Everitt and Judd, 1989; Everitt, Judd, Escobar, Davis, and others, 1996), but its distribution and that of the *Rhizophora mangle* (red mangrove) are expanding along the Texas coast as temperatures increase with climate change (Montagna and others, 2007, 2011). Fire is generally a minor influence in this community because of the high moisture content of the vegetation. This tidal system was greatly altered by construction of the Gulf Intracoastal Waterway beginning in the 1940s, effectively increasing water depths by dredging and upland habitats by deposition of dredged material. Upstream dam construction and water-flow manipulation, which reduce freshwater inputs, increase downstream salinities and reduce nutrient and sediment input to tidal estuaries in the LRGV (e.g., Cooper and Wagner, 2013).

Tamaulipan Closed Depression Wetland

The Tamaulipan Closed Depression Wetland is a freshwater to brackish-water wetland Ecological System of small and internally drained depressions (e.g., ponds and potholes) that occurs along western shorelines of Laguna Madre in Cameron and Willacy Counties, and it is an important system in Laguna Atascosa NWR. It contains nine Ecological Communities occurring rather equally in 5 of the 6 physiographic zones (table 3; Hathcock and others, 2012). Diagnostic characters include occurrence in lowland depressions; intermittent flooding, wet and dry cycles, and high rates of evaporation; sandy, wind-blown substrates but typically lined with clay or clay-loamy soils; and variable water salinity depending on freshwater input, evaporation (drawdown), and flooding. Seasonal flooding affects composition of shoreline and emergent vegetation and the degree of exposed mudflats, which can then be invaded by terrestrial vegetation. On depression wetland perimeters, Gulf cordgrass (Cooper and Wagner, 2013), sea-ox-eye daisy, saltgrass, and shoregrass occur in varied abundance depending on soil type, salinity, and elevation. As conditions become more brackish, *Schoenoplectus pungens* (common threesquare) becomes more abundant; when particularly

Figure 4. Coastal ecological systems illustrating the rich landscape and floral diversity of the coastal areas in the Lower Rio Grande Valley. *A*, Tamaulipan Ramadero associated with Tamaulipan Floodplain. *B*, Tamaulipan Loma Shrubland and Grassland. *C*, Tamaulipan Palm Grove Riparian Forest. *D*, Texas Coast Dune and Coastal Grassland. *E*, Texas Coastal and Brackish Tidal Marsh. *F*, Texas Coast Dune and Coastal Grassland. *G*, Tamaulipan Loma Shrubland and Grassland. ©Larry Ditto Nature Photography, used with permission.

wet, *Eleocharis montevidensis* (sand spikerush) can become prevalent. Subemergent vegetation in LRGV wetlands is typically dominated by the macro-alga muskgrass (*Chara* spp.) and *Ruppia maritima* (widgeongrass) when surface water is present for extended periods of time. As salinity of wetlands decreases inland, plants with floating leaves, such as *Nelumbo lutea* (American lotus) and *Nymphaea odorata* (water lily), can become established. Where not protected, some of these wetlands have been drained for agriculture, resulting in sedimentation and contamination from pesticides, fertilizer runoff, and water manipulation; they are also affected by heavy cattle grazing and oil and gas production. Wintering waterfowl species heavily use these wetlands; for example, 75 percent or more of the North American population of redheads feed on *Halodule wrightii* (shoal grass) in the most saline of wetlands.

Tamaulipan Calcareous Thornscrub

Tamaulipan Calcareous Thornscrub occurs only in Starr County on upland, calcareous, and caliche substrates with shallow soils. This Ecological System contains five Ecological Communities in 2 of the 6 physiographic zones, the Aguilares Plain and Bordas Cuesta (table 3; Hathcock and others, 2012). This system has a unique native citrus, *Helietta parvifolia* (baretta—Best, 2011a, 2011b), that grows as thickets on gravel-caliche ridges, forming an ecotone with the flood plain (fig. 3*C*). Diagnostic characters include xeric shrub dominance, occurrence on ridges or upper slopes, and very shallow soils. Dominant plant species typically are cenizo and *Senegalia berlandieri* (guajillo), and the five unique plant associations of the Tamaulipan Calcareous Thornscrub occur with various abundances of the dominants and *Vachellia rigidula* (blackbrush acacia), Texas ebony, *Salvia ballotiflora* (shrubby blue sage), *Lippia graveolens* (Mexican oregano), baretta, and even the bromeliad *Hechtia glomerata* (guapilla). This shrubland community has a shorter and more open canopy—generally less than (<) 2 m (6.6 ft)—compared with other thornscrub communities in the LRGV, growing on favorable sites with more developed soils. Other plant species include *Ziziphus obtusifolia* var. *obtusifolia* (lotebush), *Parkinsonia texana* var. *macra* (Tamaulipan palo verde), *Koeberlinia spinosa* (allthorn), and *Castela texana* (chaparro amargosa). Fire does not have much of a role in this community, except on its edges when spreading from other communities during drought and high winds.

Tamaulipan Ramadero

The Tamaulipan Ramadero, a riparian shrubland-woodland Ecological System, occurs along drainages in upland areas that ultimately drain into the Rio Grande, primarily in Starr and Hidalgo Counties. This Ecological System contains five Ecological Communities, one each in 5 of the 6 physiographic zones (table 3; Hathcock and others, 2012). Intermittent flooding affects this system, which contains isolated riparian strips of dense brush, often modified by check dams in arroyos that prevent water and nutrients from reaching them, thus reducing vegetation height and density. Under ideal conditions, stature of overstory vegetation can be 5–10 m (16.4–32.8 ft) high and closed-canopied, limiting understory density and diversity. Some sites have a shrubby, often impenetrable character of 1–5 m high (3.3–16.4 ft). Woody plant species include honey mesquite, granjeno, retama, *Condalia hookeri* (bluewood),|and *Vachellia farnesiana* var. *farnesiana* (huisache). Ramaderos provide important nesting and feeding habitats for wildlife and corridors to the Tamaulipan Floodplain along the Rio Grande (fig. 4*A*).

Tamaulipan Savanna Grassland

Remnants of the Tamaulipan Savanna Grassland, a formerly grass-dominated system, occur only on the coastal plain of northern Willacy County in the LRGV, and it contains four Ecological Communities in 3 of the 6 physiographic zones (table 3; Hathcock and others, 2012). This community was once expansive in areal coverage, typically grew on sandy or sandy-loam soils, and had a patchy and clumped overstory dominated by honey mesquite but sometimes granjeno, brasil, colima, lotebush, *Diospyros texana* (Texas persimmon), and various species of *Acacia* (Eddy and Judd, 2003). This Ecological System has been degraded by intensive livestock grazing and variation in precipitation during the past century (Archer and others, 1988; Thompson, 1997) and perhaps lack of fire, which was intentionally used by Native Americans to maintain open grassland but is now uncommon. Diagnostic characters include grass domination, patchy shrub and tree overstory, and occurrence on coastal lowlands. Dominant herbaceous species include *Bothriochloa barbinodis* (cane bluestem), *Schizachyrium scoparium* (little bluestem), *B. laguroides* var. *torreyana* (silver beard grass), four-flower trichloris, *Verbena halei* (Texas verbena), and *Rivina humilis* (pigeonberry). Today, this community is a closed shrubland, and the likelihood of reverting it to savanna grassland is slim because of the extensive restoration that would be required.

Texas Coast Dune and Coastal Grassland

The Texas Coast Dune and Coastal Grassland is a coastal Ecological System that occurs on barrier islands of the Laguna Madre and near-coastal (0–16 km) inland areas along the Gulf Coast in Cameron and Willacy Counties and is represented in parts of Laguna Atascosa NWR and Boca Chica tract in the Lower Rio Grande Valley NWR (fig. 4*D*). It contains three Ecological Communities in 3 of the 6 physiographic zones (table 3; Hathcock and others, 2012). Diagnostic characters include sand dunes, interdune swales, and barrier-flat and tidal-flat physiography; sparse vegetation; and frequent high winds and exposure to sea spray, infrequent high tides (about 20-year intervals), and storm events, which can alter vegetation and the physical nature of the system and cause movement of primary and secondary dunes (Judd and others, 2008). Leeward sides of dunes are typically the most vegetated because of protection from winds and tidal forces. Flowering flora is diverse, with at least 74 flowering angiosperms in 70 genera and 28 families on South Padre Island (Lonard and Judd, 1989). Depending on the physical landscape, this system is a matrix of grasses, typically dominated by little bluestem, *Panicum* spp., and Gulf cordgrass, but many other species of grass occur in this system (e.g., *Andropogon glomeratus* [bushy bluestem]; *A. ternarius* [splitbeard bluestem]; *Sporobolus texanus* [Texas dropseed]; and tropical grasses in the genera *Heteropogon, Paspalum,* and *Trachypogon*). Shrubs include honey mesquite, huisache, and blackbrush. Because of a lack of fire, which might have had anthropogenic origins in the past, this community can become shrub-dominated. Most of this community on the mainland has been lost to grazing and cropland.

Tamaulipan Loma Shrubland and Grassland

The Tamaulipan Loma Shrubland and Grassland occurs among plant associations of the Texas Coast Salt and Brackish Tidal Marsh system in Cameron and Willacy Counties and is an important feature of the Rio Grande Delta (e.g., Loma Preserve and Boca Chica tracts of the Lower Rio Grande Valley NWR and habitat in Laguna Atascosa NWR; fig. 4*B* and 4*G*). It contains only two Ecological Communities, both of them in the Rio Grande Delta physiographic zone (table 3; Hathcock and others, 2012). Lomas are small, xeric, subtropical, shrubby islands scattered among tidal marshes and flats, resulting from wind-blown deposits of silt, clay, and sand—typically well drained. In places, emergent trees such as Texas ebony and honey mesquite occur, but mostly the dense, thorny shrub layer is characterized by *Citharexylum berlandieri* (Berlandier's fiddlewood), *Yucca treculeana* (Spanish dagger), Texas torchwood, *Lycium berlandieri* (wolfberry), *Lantana horrida* (Padre Island lantana), blackbrush, and *Cylindropuntia leptocaulis* (tasajillo). The herbaceous understory is typically sparse because of the dense shrub canopy and includes pigeonberry, *Heliotropium curassavicum* (wild heliotrope), and *Phyla nodiflora* (Texas frogfruit). Hurricanes and tropical storms cause wind damage and saltwater inundation; outer edges of lomas can suffer from erosion during such storm events.

Texas Saline Coastal Prairies

Texas Saline Coastal Prairies occur as remnant coastal prairies on terraces of generally level topography flanking the Gulf Coast and mostly on private land in northern Willacy County. These prairies contain only two Ecological Communities in the Rio Grande Delta and Barrier Island physiographic zones (table 3; Hathcock and others, 2012). Diagnostic characters include soil saturation by local rainfall and periodic major storm events causing flooding with saline water, occurrence of both upland saline prairie and wetland community types in depressions, and microtopographic features with ridge-and-swale plant associations. Upland dominant grass species are little bluestem, *Paspalum plicatulum* (brownseed paspalum), *Sorghastrum nutans* (yellow Indiangrass), and *Andropogon gerardii* (big bluestem). Wetland dominant grasses depend on the level of disturbance: undisturbed sites have *Panicum virgatum* (switchgrass) and *Tripsacum dactyloides* (eastern gramagrass) and disturbed sites have bushy bluestem; other species of *Andropogon*, *Sporobolus*, and *Chloris*; *Carex* and *Juncus* (sedges); and various tropical genera such as *Heteropogon*, *Paspalum*, *Trachypogon*, and *Panicum*. Herbaceous forbs include *Ratibida columnifera* (prairie coneflower), *Liatris pycnostachya* (blazing-star), and *Sagittaria latifolia* (aquatic arrowhead). Honey mesquite and *Quercus* (oaks) invade this community in the absence of fire, and estimates suggest that 99 percent of this coastal prairie has been lost because of agricultural practices and disruption of natural processes.

Tamaulipan Palm Grove Riparian Forest

The Tamaulipan Palm Grove Riparian Forest is now a very unique riparian community in the LRGV (fig. 4*C*), and it is preserved only in the Rio Grande Delta physiographic zone in the Southmost Ranch and Boscaje de la Palma tracts of the Lower Rio Grande Valley NWR in extreme southern Cameron County along the Rio Grande (Everitt, Judd, Escobar, Alaniz, and others, 1996). The system is named after its diagnostic plant, *Sabal mexicana* (Rio Grande palmetto or sabal palm; fig. 4*C*). This palm was once much more common along the Rio Grande (Crosswhite, 1980). Other prominent tree species in this forested system include Texas ebony, *Ehretia anacua* (anacua), and tepeguaje; other associated riparian plants can include cedar elm and Mexican ash, trees most typical of forests in the Tamaulipan Floodplain, as well as Texas persimmon and huisache.

Tamaulipan Saline Lake

The Tamaulipan Saline Lake, a hypersaline aquatic system, is well represented in the East Lake/La Sal Vieja and La Sal del Ray/Schalaben tracts of the Lower Rio Grande Valley NWR in northern Willacy and Hidalgo Counties, respectively. Plant associations of the Tamaulipan Mixed Deciduous Thornscrub Ecological System typically surround these saline lakes. Sparse to moderate vegetation cover occurs on the edges of these lakes, dominated by halophytic grasses and small shrubs. The lakes provide migrating and wintering habitat for *Aythya affinis* (lesser scaup), *Oxyura jamaicensis* (ruddy ducks), *Dendrocygna autumnalis* (black-bellied whistling ducks), *Pelecanus erythrorhynchos* (white pelicans), and sandhill crane. Ten percent of the North American population of the long-billed curlews winters at East Lake (Covington, 2014).

Seagrass Meadows of Laguna Madre

Laguna Madre is the largest of seven estuarine systems on the Texas coast and, along with the Laguna Madre de Tamaulipas of Mexico, is 1 of only 5 hypersaline ecosystems in the world (Tunnell, 2002a; Webster and others, 2002). In the United States, Laguna Madre is protected on the west by Padre Island, the longest barrier island in the world. The lagoon has an average depth of only about 1 m (3.3 ft), and seagrass meadows cover about 65 percent on its bottom (Onuf, 1996b, 2007; Tunnell and Judd, 2002; Mendoza and others, 2011; fig. 5). Just east of the LRGV, the Lower Laguna Madre contains abundant seagrass meadows of shoal grass, *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass), *Ruppia maritima* (widgeongrass), and *Halophila engelmannii* (star grass) that provide vital resources for wintering waterfowl, notably shoal grass for redheads (Smith, 2002a), and nurseries for fish, shrimp, and other marine life (e.g., Sheridan and Minello, 2003). Herbivory by such organisms is now seen as a fundamental process in seagrass meadows (Tolan and others, 1997; Valentine and Heck, 1999; Hemminga and Duarte, 2000; Withers, 2002a; Sheridan and Minello, 2003; Valentine and Duffy, 2006). Laguna Madre and associated terrestrial areas are part of UNESCO's Man and the Biosphere Programme, designated as a Ramsar Convention Wetland of International Importance, and recognized as a site of international importance by the Western Hemisphere Shorebird Reserve Network (Tunnell and Judd, 2002; Mendoza and others, 2011).

Seagrass meadows are ecologically dynamic (Duarte, 2002; Withers, 2002a). Wind tides, tropical and northern storms, and phytoplankton blooms, for example, greatly modify seagrass meadows and change biotic communities that depend on them (Tunnell, 2002a, 2002b; Withers, 2002d). Phytoplankton-caused brown tides have likely shaped seagrass meadows in Laguna Madre for thousands of years, although

Figure 5. Shallow-water seagrass meadows, a dominant feature of the Lower Laguna Madre offshore of the Lower Rio Grande Valley. Seagrass meadows provide critical habit for many marine and wetland bird species and can be damaged by inadvertent boating activity, as shown in the bottom-right image. Top and bottom-right images from ©Gywn Carmean and bottom-left image from ©Larry Ditto Nature Photography, all used with permission.

historical records of their occurrences are quite uncommon (Withers, 2002a). A recent 6–7-year brown tide, caused by the alga *Aureoumbra lagunensisi* (DeYoe and others, 1997) in the Upper Laguna Madre, began in the early 1990s and ended in 1997 (e.g., Rhudy and others, 1999; Onuf, 2000; Withers, 2002d); photosynthesis, elemental metabolism, and productivity of seagrass meadows and changing community composition relative to the persistent algal bloom were studied in the entire Laguna Madre (appendix *A*). Onuf (2007) noted that because precipitation is generally low and surrounding landscapes of the Laguna Madre are flat, there is little input of nutrients and sediments, resulting in typically clear water (fig. 5). The algal bloom, however, altered the upper lagoon's water clarity and light penetration and thereby reduced productivity and overall coverage of seagrass meadows. The algal bloom was likely caused by hard freezes in 1989 and 1990 (Lonard and Judd, 1991) during drought that caused extensive mortalities of fish and benthic organisms—the pulse of nutrients that fueled the algal bloom (DeYoe and Suttle, 1994; Rhudy and others, 1999; Withers, 2002d). Toxic red tides caused by dinoflagellates occur in Laguna Madre but are rare compared with brown tides (Withers, 2002d).

Boating and dredging activities, mainly to establish waterways and keep them open to boats, can directly destroy seagrass meadows (fig. 5) and increase turbidity that decreases seagrass meadow productivity and long-term survival and that of dependent biota (Quammen and Onuf, 1993; Onuf, 1994; Martin and others, 2008; Larkin and others, 2010). In the Upper Laguna Madre, 14.5–97.6 percent of extensive seagrass areas, with depths generally <1 m (3.3 ft), were lightly scarred (<5 percent of the study area covered by propeller scars), moderately scarred (5–20 percent), and severely scarred (greater than [>] 20 percent); on Estes Flats alone, 97.6 percent of the 1,258.2 ha (3,109 acres) sampled was damaged—948.7 ha (2,344 acre) of them severely—by propellers on recreational boats (Dunton and Schonberg, 2002). Recolonization of damaged areas is species-specific; long-lived, slow-growing seagrasses such as turtle grass recolonize slowly after damage, whereas fast-growing species such as shoal grass invade more rapidly if conditions are favorable (Dunton and Schonberg, 2002). Comparable studies have not been conducted in the Lower Laguna Madre (Tunnell, Withers, and Smith, 2002).

Restoration of seagrass meadows has met with limited success; at disposal sites of dredging materials just north of Brazos Santiago Pass in the Lower Laguna Madre, wind-driven resuspension of dredging materials decreased light penetration and increased sediment ammonium, both of which decreased revegetation success of shoal grass (Kaldy and others, 2004). Onuf (1994) noted the greatest losses of seagrasses due to decreased light penetration nearest disposal sites of dredged materials near Port Mansfield, with negative effects detectable up to 1.2 km (0.7 mi) away.

Onuf (2007) provided a comprehensive summary of seagrass changes from the mid-1960s to 1998 in the entire Laguna Madre, which contains 75–80 percent of the seagrass meadows on the entire coast of Texas (Gutierrez and others, 2010). A critical phase in the dynamics of seagrass meadows in the Lower Laguna Madre of the LRGV occurred from 1965 to 1974 when 118 square kilometers (km^2) (45.5 square miles [mi^2]) of meadows became bare (Onuf, 1994), as a result of ongoing dredging and maintenance of the Gulf Intracoastal Waterway, initially dug in the 1940s; such activities increase turbidity and decrease productivity of seagrass. Maintenance of the Gulf Intracoastal Waterway and developments such Port Mansfield Channel and Brazos Santiago Pass also allowed more regular exchange of water between the Upper and Lower Laguna Madre and the Gulf of Mexico, respectively, reducing the historically hypersaline characteristics of the lagoon. Coverage of shoal grass—the most salt tolerant seagrass—in the Lower Laguna Madre declined from 89 percent in the mid-1960s to only 46 percent in 1998, likely because reduced salinity allowed expansion of less salt-tolerant but more competitive manatee grass and turtle grass (e.g., turtle grass increased from a mere 436 ha [1,077 acres] in the mid-1960s to 11,132 ha [27,507 acres] in 1998); similar changes occurred in the Upper Laguna Madre (Onuf, 2007; Gutierrez and others, 2010). Changing dynamics of seagrass meadows, particularly abundance of shoal grass, need to be carefully monitored because they are inextricably linked to viability of the continental population of redheads, other waterfowl, resident fishes, and other fauna living in them (e.g., Mitchell, 1991; Mitchell and others, 1994; Custer and others, 1997; Bergan, 2002; Sheridan and Minello, 2003).

Restoration of Threatened Plant Communities

Most, if not all, of the native forests and subtropical brushlands in the expansive 1.1 million ha (2.7 million acres) of the LRGV are threatened by ongoing human activities, particularly population growth, agriculture, urbanization (e.g., Ewing and Best, 2004; Twedt and Best, 2004; Tremblay and others, 2005), and illegal foot traffic and subsequent border patrol activities, including road construction. Native riparian forests of Mexican ash, cedar elm, and sugarberry have been greatly diminished by clearing, periodic droughts leading to habitat xerification (Gehlbach, 1987; Brush, 2005), and especially the many hydrological alterations to the Rio Grande, minimizing seasonal flooding on which flood plain vegetation depends or, on the contrary, permitting long and harmful inundation. The largest remaining relatively intact forest of this kind occurs in Santa Ana NWR in the mid-LRGV (Vora, 1990a, 1990b), but it can be challenged by persistent inundation, such as that which occurred for 5–8 months in 2010, killing many mature trees. Communities of honey mesquite, granjeno, Texas ebony, and brasil once covered much of the alluvial plain of the LRGV, but their coverage has been reduced to <5 percent of what it once was (Parvin, 1988a, 1988b; Raney and others, 2004; Tremblay and others, 2005). Upland thornscrub communities have been less affected than plant communities of the Rio Grande flood plain, but heavy grazing, invasive grasses, and the expanding human population and its associated activities continue to threaten them (e.g., Vora and Messerly, 1990).

Restoration of threatened plant communities has been and is currently an important focus for managers of State and Federal properties in the LRGV (e.g., Vora, 1992; Judd and others, 2002; Sternberg, 2003; Adhikari and White, 2014). Twedt and Best (2004) provided a historical overview of restoration activities from which most of the following synthesis was derived, supplemented with records of the Lower Rio Grande Valley NWR (B. Barry, written commun.). The first documented habitat restoration in the LRGV was conducted at the Las Palomas (meaning "doves" in Spanish) Wildlife Management Area (WMA) by TPWD in the late 1950s (Judd and others, 2002), with a focus on improving habitat and hunting opportunities for *Zenaida asiatica* (white-winged doves).

Initial restoration work of acquired croplands in the Lower Rio Grande Valley NWR began in the early 1980s and continued through the mid-1990s (Vora, 1992; Twedt and Best, 2004). It largely focused on direct seeding of fast-growing, woody legumes (Texas ebony, huisache, and tepeguaje) in strips in abandoned cropland; associated experiments were conducted on techniques to enhance seed germination (Vora, 1989a; Vora and Labus, 1988; Vora and others, 1988). The goal was to provide quick cover at "a low cost, suppress weeds, and attract seed-dispersing fauna" and thereafter let secondary succession naturally restore the former cropland to native habitats (Twedt and Best, 2004, p. 199). Seed plantings were mostly abandoned in 1995 because of unreliable germination, availability of seeds, and low success and lack of diversity from planting seeds directly.

With foresight gained from restoration of native shrublands and forests (Vora, 1992; Twedt and Best, 2004), the Lower Rio Grande Valley NWR established physical facilities and species-specific protocols for greenhouse production of native plant species to be used in restoration operations. A single restoration site may be planted with 30–40 species of trees, shrubs, and cacti (Twedt and Best, 2004), resulting in more diverse communities in a shorter amount of time than unaided communities (Judd and others, 2002; Sternberg, 2003). It typically takes 3–5 years to judge the success of a planting. From 1995 to 2011, more than 3 million seedlings were planted in the Lower Rio Grande Valley NWR (fig. 6*A*); plantings occur in September–November when soil moisture

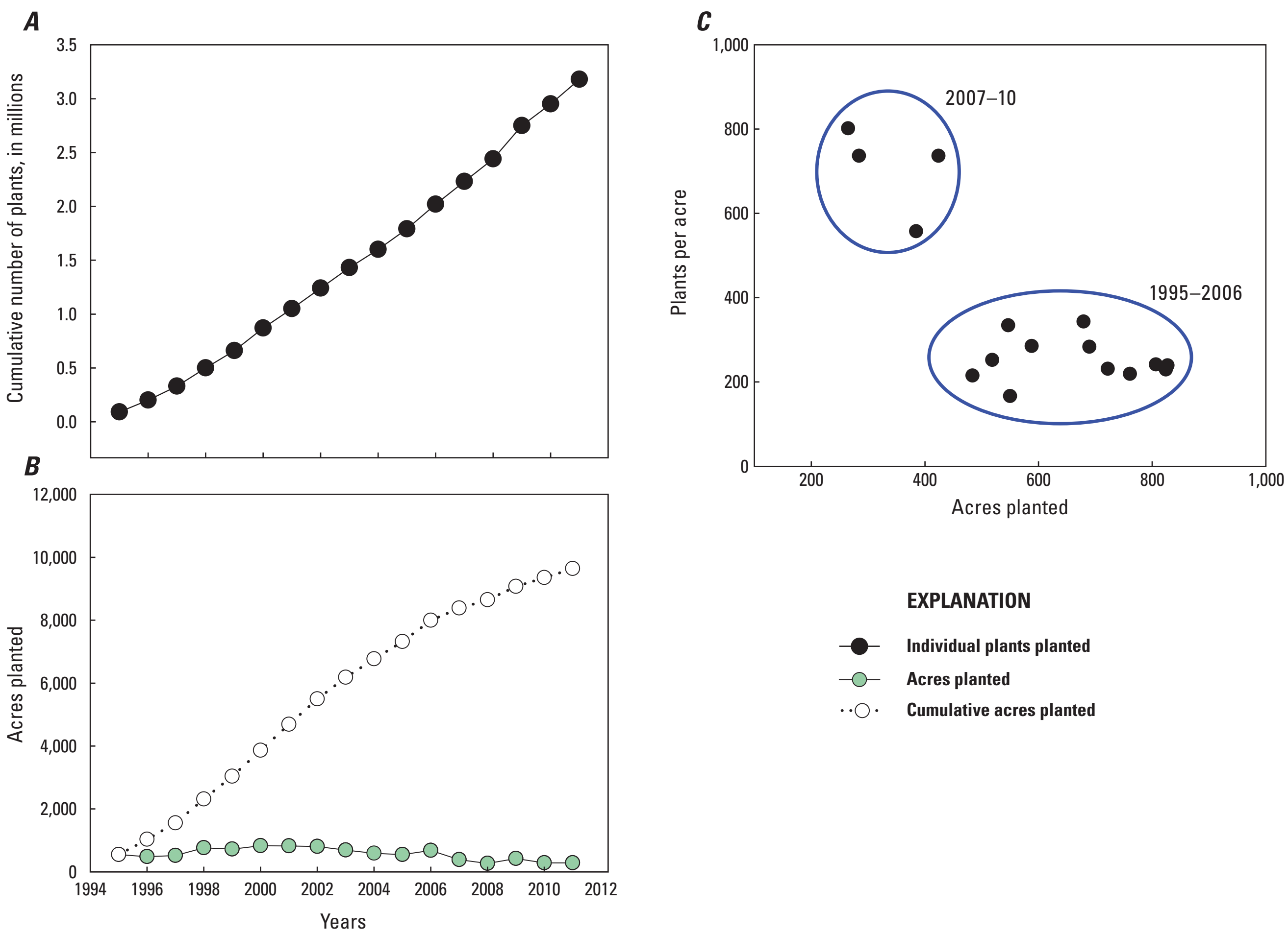

Figure 6. Restoration activities conducted by the U.S. Fish and Wildlife Service in the Lower Rio Grande Valley National Wildlife Refuge from 1995 through 2012. *A*, cumulative number of plants. *B*, acres planted. *C*, plants per acre and acres planted.

is typically replenished and cool weather enhances seedling survival. An average of 186,000 seedlings was planted each year, with about 127 seedlings planted per hectare (314 seedlings planted per acre). The Lower Rio Grande Valley NWR itself produces about 85,000 seedlings per year from more than 60 native plant species in its own greenhouse facility near Santa Ana NWR, and private nurseries provide the rest. Production and planting of refuge stock peaked in 2008 with 121,100 seedlings produced, or 57.1 percent of the 212,047 total seedlings planted. An average of 567 acres (229.5 ha) has been planted annually in the Lower Rio Grande Valley NWR, with just about 10,000 acres (4,047 ha) being restored since 1995 (fig. 6*B*). Through time, the number of acres planted annually decreased, but the number of seedlings planted per acre and their survival increased (fig. 6*C*). Since 1997, the Lower Rio Grande Valley NWR has held the annual Rio Restoration in October, using up to 1,000 volunteers to plant tree and shrub seedlings (now protected in tubes—Dick, 2015). To date, volunteers have planted about 200,000 seedlings on about 250 ha (620 acres). Availability of native seedlings is currently the primary limitation to restoration efforts. Native plants of southern Texas are not commercially or locally available. The only native plant growers are contracted by the USFWS to grow native species for restoration activities in the LRGV.

Many restorations in the LRGV have involved old croplands (fig. 7) with soils depleted in organic matter (Vora and Jacobs, 1990), and site preparation can involve a no-till approach or a more traditional approach of shredding crop residue (if present), chisel plowing to a depth of greater than or equal to (≥) 38 centimeters (cm) (15 inches [in.]), and disking to break up the soil and create planting rows or beds. Herbicide applications before and after planting might be needed to control invasive species, particularly Asian and African grasses (e.g., *Megathyrus maximus* [guineagrass], *Sorghum halepense* [Johnson grass]; *Cynodon dactylon* [Bermudagrass], *Bothriochloa ischaemum* var. *ischaemum* [King Ranch bluestem]; and *Dichanthium annulatum* [Kleberg bluestem]; Twedt and Best, 2004; Falk and others, 2012).

Trends in community development on restored sites are strongly influenced by soil moisture at the time of planting, planting pattern, characteristics of edge communities associated with the restoration site, and competitive interactions from early, naturally invading successional species; survival of transplants is associated with site conditions at the time of planting—a balancing act of planting at times of optimal soil moisture but when the soil is not so wet that equipment has difficulty entering a site (Ewing and Best, 2004). Restoration methods and results vary (fig. 7): compared to a desired canopy cover baseline of 87 percent, restorations have changed from a mere 0.2 percent canopy cover after initial planting to 2.1–8.8 percent after 3 years post-planting to 17.6–33.4 percent after 6 years post-planting (Ewing and Best, 2004).

Recent assessments suggested that 15–25-year-old revegetated tracts in the Lower Rio Grande Valley NWR had similar woodland bird communities as mature woodland habitat, except mature tall riparian forest that is hard to maintain and restore unless close to the Rio Grande (Brush and Feria, 2015). Small mammal communities in replanted former agricultural fields were comparable to native thornscrub woodlands (Sternberg and Judd, 2006; see “Small Mammals” subsection of this report). Relative to restoring habitat for northern ocelots, Young and Tewes (1994) evaluated tree shelters, fertilizer, tree branch trimming, and elimination of herbaceous growth to increase and enhance growth of woody seedlings. Tree shelter tubes increased survival and growth of seedlings but not weeding, clipping, or fertilizing (Young and Tewes, 1994; USFWS, 2010a). Recent research suggests that shelter tubes, grass-specific herbicide, and herbivore exclusion facilitate faster, efficient, and effective thornscrub restoration (Dick, 2015; Alexander and others, 2016), and increasing seedling density may provide positive synergistic effects among adjacent or grouped seedlings (M. Sternberg, written commun.).

Twelve cooperators still farm 2,505 ha (6,189 acres) in the Lower Rio Grande Valley NWR until native plants are available to restore the natural vegetation. Eight of these 12 farmers grow “dryland” crops because most farmland purchased by the Lower Rio Grande Valley NWR has nonfunctional or dilapidated irrigation systems; five farmers have access to irrigation and pay higher rent per unit area to USFWS than the others. In exchange for paying rent to use tracts in the Lower Rio Grande Valley NWR, farmers can purchase and plant seedlings of native species used in the restoration program and also conduct in-kind services that provide equipment and labor to remove invasive grasses (see “Exotic and Invasive Species” section) and conduct follow-up care of tracts that have been restored. The pace of habitat restoration is often impeded by limited availability of native seedlings.

Threatened and Endangered Plants

Overview

In the LRGV, at least 24 plant species, representing 18 families, are considered officially endangered by Federal and State agencies or are rare enough to be of global conservation concern (Poole and others, 2007, 2010; table 5). Six of these plant species, representing five families, are on both Federal and State lists of endangered and threatened species (Poole and others, 2010): *Thymophylla tephroleuca* (ashy dogweed), *Ambrosia cheiranthifolia* (South Texas ambrosia), *Astrophytum asterias* (star cactus), *Ayenia limitaris* (Tamaulipan kidneypetal or Texas ayenia), *Manihot walkerae* (Walker’s manioc), and *Physaria thamnophila* (Zapata bladderpod—Wu and Smeins, 2000). *Frankenia johnstonii* (Johnston’s frankenia) was listed as endangered in 1985 and was proposed for delisting in 2003 and 2011 because of the discovery of additional populations in Texas (Starr, Webb, and Zapata Counties) and Mexico, including on tracts of the Lower

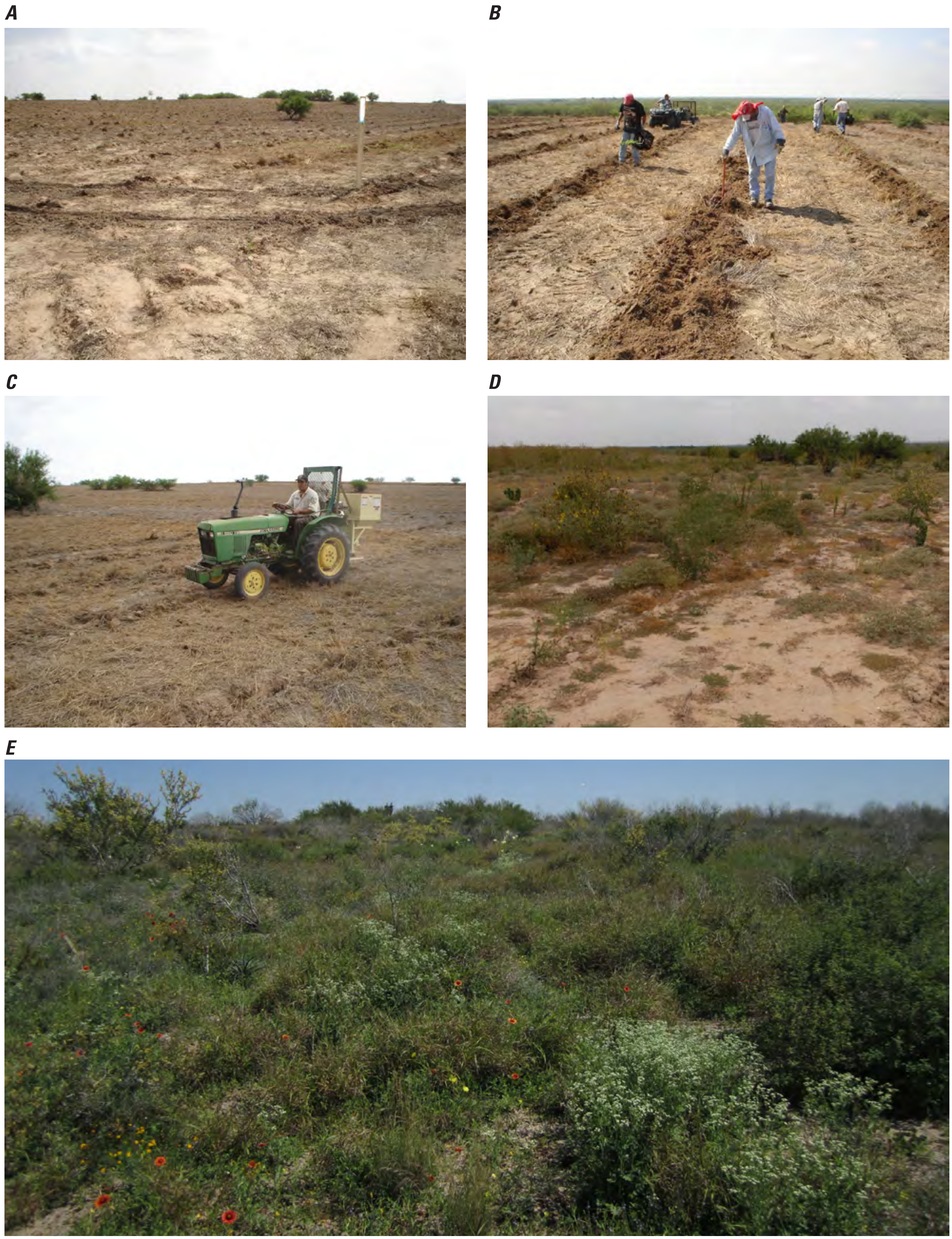

Figure 7. Restoration of old cropland to native forest and brushland, a high conservation priority in the Lower Rio Grande Valley National Wildlife Refuge. Restoration sequence of the Sam Fordyce tract: *A*, preplanting in October 2007; *B*, seedling planting by hand in October 2007; *C*, direct seeding of grasses and herbaceous plants with a tractor; *D*, restoration progress by July 2008; and *E*, restoration success by March 2015. Photographs courtesy of Kim Wahl, U.S. Fish and Wildlife Service.

Table 5. Endangered and rare plant species found in the four-county area of the Lower Rio Grande Valley in southern Texas, from the Annotated County Lists of Rare Species by Texas Parks and Wildlife Department (2014), NatureServe (2013), U.S. Fish and Wildlife Service Federal listings, and Poole and others (2010).

[Federally or State listed as E, endangered; T, threatened; C, candidate species; R, rare in Texas but with no regulatory status; DL, delisted, January 2016. NatureServe's G1 or S1, critically imperiled globally or subnationally, in this case Texas; G2 or S2, imperiled and very vulnerable; G3 or S3, vulnerable; G4 or S4, apparently secure; G5 or S5, secure; T, infraspecific classifications that follow the same status as G and S; GH, SH, or H, historical occurrence/possibly extinct or extirpated; SX, presumed extirpated/extinct; B, breeding]

	Listing		Rank		
FAMILY/Species	**Federal**	**State**	**Global**	**State**	**County occurrence**
ACANTHACEAE					
Justicia runyonii (Runyon's water-willow)		R	G2	S2	Cameron, Hidalgo, Willacy
AMARANTHACEAE					
Atriplex klebergorum (Kleberg saltbush)		R	G2G3	S2S3	Starr
ASCLEPIADACEAE					
Asclepias prostrata (prostrate milkweed)		R	G1G2	S1S2	Starr
Matelea radiata (Falfurrias milkvine)		R	GH	SH	Hidalgo (H)
ASPARAGACEAE					
Echeandia chandleri (lila de los llanos)		R	G2G3	S2S3	Cameron
Echeandia texensis (Texas craglily)		R	G1	S1	Cameron
Manfreda longiflora (Runyon's huaco)		R	G2	S2	Hidalgo, Starr
ASTERACEAE					
Ambrosia cheiranthifolia (South Texas ambrosia)	E	E	G2	S2	Cameron (H)
Grindelia oolepis (plains gumweed)		R	G2	S2	Cameron
Thymophylla tephroleuca (ashy dogweed)	E	E	G2	S2	Starr (H)
BRASSICACEAE					
Physaria thamnophila (Zapata bladderpod)	E	E	G1	S1	Starr
Thelypodiopsis shinnersii (Shinner's rocket)		R	G2	S2	Starr (H)
BROMELIACEAE					
Tillandsia baileyi (Bailey's ballmoss)		R	G2G3	S2	Cameron, Hidalgo, Starr
CACTACEAE					
Astrophytum asterias (star cactus)	E	E	G2	S1S2	Cameron, Hidalgo (H), Starr
Coryphantha macromeris ssp. *runyonii* (Runyon's cory cactus)			T2T3	S2S3	Cameron, Hidalgo, Starr
COMMELINACEAE					
Tradescantia buckleyi (Buckley's spiderwort)		R	G2	S2	Cameron (H)
EUPHORBIACEAE					
Manihot walkerae (Walker's manioc)	E	E	G2	S1	Hidalgo, Starr
FABACEAE					
Dalea austrotexana (dune dalea)		R	G2	S2	Cameron
FRANKENIACEAE					
Frankenia johnstonii (Johnston's frankenia)	DL	E	G3	S3	Starr
MALVACEAE					
Ayenia limitaris (Tamaulipan kidneypetal)	E	E	G2	S1	Cameron, Hidalgo, Willacy
Wissadula parviflora (small-leaved yellow velvet-leaf)		R	G1	S1	Hidalgo

Table 5. Endangered and rare plant species found in the four-county area of the Lower Rio Grande Valley in southern Texas, from the Annotated County Lists of Rare Species by Texas Parks and Wildlife Department (2014), NatureServe (2013), U.S. Fish and Wildlife Service Federal listings, and Poole and others (2010).—Continued

[Federally or State listed as E, endangered; T, threatened; C, candidate species; R, rare in Texas but with no regulatory status; DL, delisted, January 2016. NatureServe's G1 or S1, critically imperiled globally or subnationally, in this case Texas; G2 or S2, imperiled and very vulnerable; G3 or S3, vulnerable; G4 or S4, apparently secure; G5 or S5, secure; T, infraspecific classifications that follow the same status as G and S; GH, SH, or H, historical occurrence/possibly extinct or extirpated; SX, presumed extirpated/extinct; B, breeding]

	Listing		Rank		
FAMILY/Species	**Federal**	**State**	**Global**	**State**	**County occurrence**
NYCTAGINCEAE					
Abronia ameliae (Amelia's abronia)		R	G2	S2	Hidalgo (H)
POLYGONACEAE					
Eriogonum greggii (Gregg's wild-buckwheat)		R	G2	S1	Hidalgo (H), Starr
PONTEDERIACEAE					
Heteranthera mexicana (Mexican mud-plantain)		R	G2G3	S1	Cameron (H), Hidalgo (H)
SAPINDACEAE					
Cardiospermum dissectum (Chihuahua balloon-vine)		R	G2G3	S2S3	Hidalgo, Starr

Rio Grande Valley NWR, bringing the number of known populations from six in 1984 to about 84 in 2015. Johnston's frankenia was just delisted in 2016 (U.S. Department of Interior, Fish and Wildlife Service, 2016). Two areas in the LRGV are hotspots of occurrence for these endangered plants: the Rio Grande Delta in Hidalgo and Cameron Counties and upland areas in Starr County, where 4 of 6 endangered taxa are known to occur (table 5).

Habitat loss and modifications are at least partly to blame for the decline in these plant species (Wu and Smeins, 2000). Additional threats include overcollection, particularly of the star cactus, and lack of genetic diversity caused by very small population sizes (USFWS, 2003). Currently, the USFWS and other conservation groups protect and restore endangered plants in the LRGV; conservation efforts include purchasing lands on which these endangered plant species grow, cataloging Global Positioning System (GPS) locations of where individual plants are growing to enhance protection (USFWS, 1997), and cultivating some of these plants for future restoration efforts. GPS technology is being used to identify and map potential areas of occurrence, based on ecological requirements of these species and areas for possible restoration efforts in the LRGV (Wu and Smeins, 2000).

Ashy Dogweed

Ashy dogweed is in the sunflower family (Asteraceae) and was listed as federally endangered in 1984 (Poole, 1987). This herbaceous perennial has bright yellow flowers, and its stems are covered with ashy-white wooly hairs. It grows in dense clusters after rains and prefers disturbed sandy to sandy-loam soils on gentle topography. It was first discovered in Starr County in 1932 but no longer occurs there (Poole, 1987). Currently, the only known location of the ashy dogweed is just west, outside the LRGV proper in Zapata County. It now grows in a mixed cenizo-blackbrush community—an area that may have been originally native grassland (Poole, 1987). Grazing, habitat clearing, and competition with exotic species such as *Cenchrus ciliaris* (buffelgrass) likely led to its endangered status. The present population in Zapata County also may be threatened by use of roadside herbicides because it mainly occurs in right-of-ways (Poole, 1987). It has been propagated successfully by the San Antonio Botanical Center, which may prove useful to its recovery.

South Texas Ambrosia

South Texas ambrosia was federally listed as endangered in 1993 (USFWS, 2010c). It is a clonal, perennial member of the sunflower family, and each individual may have hundreds of stems (fig. 8*B*). It was historically native to Cameron County in the LRGV, but it is no longer found there. Its most recent 5-year review showed that 8 of 14 known populations had been lost; the 6 remaining populations are isolated in Nueces and Kleberg Counties, Tex., just north of the LRGV (USFWS, 2010c). It is also found in northern Tamaulipas, Mexico (Poole and others, 2010). It grows in grasslands and mesquite-dominated shrublands and has declined because of intense cultivation of the coastal prairie (Poole and others, 2010). Most remnant populations occur in areas that have never been plowed (e.g., railroad and highway rights-of-ways and cemeteries). Even in these areas, South Texas ambrosia is threatened by encroachment of invasive grasses (Poole and others, 2010), more than any other known threat (USFWS, 2010c). South Texas ambrosia is easy to propagate, enhancing recovery options.

Figure 8. Endangered plants of the Lower Rio Grande Valley. *A*, *Ayenia limitaris* (Tamaulipan kidneypetal). *B*, *Ambrosia cheiranthifolia* (South Texas ambrosia). *C*, *Astrophytum asterias* (star cactus). *D*, *Physaria thamnophila* (Zapata bladderpod). *E*, *Manihot walkerae* (Walker's manioc). Photographs courtesy of Chris Best, U.S. Fish and Wildlife Service.

Star Cactus

The federally endangered star cactus (Cactaceae) was historically native to Starr, Hidalgo, and possibly Cameron Counties in the LRGV and adjacent Zapata County and in the Mexican States of Nuevo León, Tamaulipas, and Coahuila (Poole and others, 2010; fig. 8*C*). It is now found only in Starr County and a few areas in Nuevo León and Tamaulipas, and it does not occur on any tracts of the Lower Rio Grande Valley NWR (USFWS, 2003). Star cacti grow on gentle slopes and flats in sparsely vegetated areas in mesquite grasslands and shrublands (Poole and others, 2010). It is completely dependent on pollination by insects to reproduce (Strong, 2005; Strong and Williamson, 2007; Blair and Williamson, 2008), and 4 of 5 populations examined had high genetic diversity (Terry, 2005; Terry and others, 2006, 2012). Star cacti in Mexico are particularly susceptible to mortality from a plant pathogen (*Phytophtora infestans*), a cerambycid beetle, and *Ictidomys mexicanus* (Mexican ground squirrel), which can reduce a population by 50 percent (Martínez-Ávalos and others, 2007). In the United States, principal causes for decline are habitat clearing and overgrazing; in Mexico, very little suitable habitat remains, lost to orange groves and corn fields (USFWS, 2003). Because of its unique appearance, the star cactus is very popular among cacti enthusiasts, and it continues to be illegally harvested.

Tamaulipan Kidneypetal

The spineless subshrub Tamaulipan kidneypetal (fig. 8*A*), newly assigned to the family Malvaceae, was listed as federally endangered in 1994 (Poole and others, 2010; USFWS, 2010d) and has a recently drafted recovery plan (USFWS, 2014a). There are five populations in Hidalgo, Cameron, and Willacy Counties of the LRGV: four of them with 100–200 individuals (one population in the Lower Rio Grande Valley NWR) and the fifth with about 1,000 individuals (USFWS, 2010d). Tamaulipan kidneypetal occurs only in the Mexican state of Tamaulipas at 14 sites with about 4,000 individuals (USFWS, 2014a). Partially shaded edges of well-drained subtropical thorn woodland or savanna, rather than dense woodland, in the Rio Grande Delta are its optimal habitats (Poole and others, 2010; USFWS, 2014a). The Lower Rio Grande Valley NWR has actively participated in its recovery with successful germination, propagation, and reintroduction activities. Tamaulipan kidneypetals were successfully reintroduced at 3 of 4 locations in the LRGV, with one population growing from 84 seedlings in 1999 to 295 individuals in 2008 (USFWS, 2014a). Main threats to Tamaulipan kidneypetals are brush clearing for agriculture and urbanization and competition with exotic grasses, mainly guineagrass.

Walker's Manioc

Walker's manioc is in the family Euphorbiaceae (Poole and others, 2010) and was listed as federally endangered in 1991 (USFWS, 2009). In the United States, it is limited to Hidalgo and Starr Counties in the LRGV and Duval County just to the north; it also occurs in Tamaulipas, Mexico (Poole and others, 2010). Walker's manioc is a perennial vine-like subshrub (fig. 8*E*) that grows in semiarid, shaded shrublands on xeric slopes and uplands, often overexposed caliche outcrops (Clayton, 1993; Poole and others, 2010). It occurs at only 9 sites in the United States, with 3 of the largest sites in the Lower Rio Grande Valley NWR, and 24 sites in Tamaulipas, Mexico. Population sizes range from only one individual to about 90 individuals (USFWS, 2009). Invasive grasses, chemical runoff, and herbicides from nearby cultivated fields threaten remnant populations (Clayton, 1993). Major causes for decline of Walker's manioc are clearing for agriculture, oil and gas development, surface mining for caliche, and urbanization (Clayton, 1993; USFWS, 2009). The San Antonio Botanical Garden and the Lower Rio Grande Valley NWR have developed techniques to propagate Walker's manioc from seeds and tubers, but reintroduction criteria relative to recovery objectives have not been formalized (USFWS, 2009). A 5-year status review was initiated in April 2015.

Zapata Bladderpod

The Zapata bladderpod is part of the mustard family Brassicaceae (Poole and others, 2010; fig. 8*D*) and was listed as endangered in 1999. In the United States, it occurs only in Starr County of the LRGV and adjacent Zapata County; in Mexico, it occurs in Tamaulipas (USFWS, 2004; Poole and others, 2010). Only eight populations were known in 2005 (Sternberg, 2005). This short-lived perennial grows in clumped distributions on upland terraces of gravelly to sandy-loam soil above the Rio Grande flood plain. It is typically occurs with canopy associates (22 canopy species at one site), preferring a moderate degree of overstory cover, particularly as seedlings (Sternberg, 2005; Fowler and others, 2011). Population sizes vary considerably; one population in Starr County varied from about 826 individuals to 8,351 individuals over an 8-year period (Sternberg, 2005). In contrast, 2 of the 4 populations studied by Fowler and others (2011) had 2,000–78,000 individuals, but none of them were reproductive in 2006. Road construction, oil and gas exploration, agriculture, and livestock grazing are principal causes of decline (USFWS, 2004). Recovery of the Zapata bladderpod may be best achieved by providing sufficient litter cover to enhance germination and seedling growth, reducing dense shrubby overstory to moderate levels with a minimum of soil disturbance, and eliminating invasive grasses (Fowler and others, 2011).

Faunal Characteristics

Conservation-related resources of the USFWS list 429 species of birds, 44 species of mammals, 115 species of reptiles and amphibians, and 31 species of fishes occurring in the STRC at some time during the year (Perez, 2014). Invertebrates of the LRGV include about 300 species of butterflies (about 280 confirmed and about 20 hypothetical) and more than 100 species of dragonflies and damselflies, as well as many freshwater, brackish, and marine aquatic invertebrates such as mollusks and shrimp. Invasive exotic species also occur in the STRC (see "Exotic Species" section), with varying degrees of impact and managerial concern: vertebrates including *Myocastor coypus* (nutria), *Sus scrofa* (feral hog), and *Boselaphus tragocamelus* (nilgai) and invertebrates including *Solenopsis* spp. (fire ant), *Apis mellifera* (Africanized honey bee), and *Litopenaeus vannamei* (Pacific shrimp).

Eighty-five species of invertebrates and vertebrates that occur in the STRC, or have historically, are federally or State listed as endangered, threatened, or rare: 3 mussels, 13 insects, 6 amphibians, 7 fishes, 15 reptiles, 29 birds, and 12 mammals (table 6). Several species are only historically known from the LRGV and are effectively now extirpated; for example, *Quadrula mitchelli* (false spike mussel), *Cicindela nigrocoerulea subtropica* (subtropical black sky tiger beetle), *C. obsoleta neojuvenilis* (neojuvenile tiger beetle), *Eximacris superbum* (superb grasshopper), *Hybognathus amarus* (Rio Grande silvery minnow), *Numenius borealis* (Eskimo curlew, perhaps extinct throughout its entire distribution), and *Panthera onca* (jaguar). The endemic *Opilidia chlorocephala smythi* (Smyth's tiger beetle) from Cameron County is likely extinct. Critical habitat has been designated for the federally threatened *Charadrius melodus* (piping plover) within the STRC in Cameron and Willacy Counties. Although the Gulf Coast jaguarundi is extremely rare, one was killed on a highway just east of Brownsville, Tex., in 1986, and several sightings have been made since then (B.R. Winton, oral commun.). In the late 1980s, the list of endangered species in the LRGV included the *Pelecanus occidentalis* (brown pelican), *Haliaeetus leucocephalus* (bald eagle), and *Falco peregrinus* (peregrine falcon); all three species recovered and were removed from the USFWS Endangered Species List.

Invertebrates

Diversities of aquatic and terrestrial invertebrates in the LRGV and the associated Lower Laguna Madre are no doubt high but little studied. Economically important terrestrial species, such as those considered as agricultural pests, have been studied the most (see "Pesticides" section). In the only study on freshwater bivalves in the Rio Grande since the late 1980s, nine species of unionids (e.g., *Anodonta* spp. and *Uniomerus* spp.), two species of fingernail clams (*Sphaerium* spp.), and the introduced *Corbicula fluminea* (Asian clam) were most closely associated with remnant free-flowing parts of the Rio Grande and associated resacas (Neck and Metcalf, 1988). Research on other aquatic invertebrates in the Laguna Madre has been limited to several species of mollusks (*Mercenaria* spp. [hard clams]—Dillon and Manzi, 1989; invasive *Perna perna* [brown clam]—Hicks and Tunnell, 1993; and *Crassostrea virginica* [American oyster]—Fredensborg and others, 2013) and crabs (*Callinectes sapidus* [blue crab]—Kordos and Burton, 1993—and five species of *Uca* spp. [fiddler crabs]—Thurman 1998a, 1998b), with new records of occurrence for natant decapods (*Pontonia domestica* and *P. floridanus*—Strenth and Chace, 1995) and *Aplysia cervina* (sea hare—Strenth and Littleton, 1994).

The most economically important commercial and artisanal fisheries in Laguna Madre of Texas (Withers and Dilworth, 2002) and Mexico (Pérez-Castañeda and others, 2012) focus on penaeid shrimp. *Farfantepenaeus duorarum* (northern pink shrimp) and *F. aztecus* (northern brown shrimp) are most abundant in the Lower Laguna Madre east of the LRGV, and *Litopenaeus setiferus* (white shrimp) are found mostly in areas from Port Mansfield to South Bay off Willacy and Cameron Counties in the LRGV. Post-larval and juvenile penaeid shrimp are a foundational part of the food web and most common in lagoons, with adults found mainly offshore; pink shrimp in particular depend on productive, dense seagrass meadows in waters east of the LRGV (Withers and Dilworth, 2002). Commercial shrimp farming of primarily exotic Pacific shrimp (Balboa and others, 1991; Wakida-Kusunoki and others, 2011) has expanded in the LRGV since the late 1980s (e.g., Baker, 1997; Ritvo and others, 1998), bringing the risk of environmental contamination (e.g., hypernutrification of estuarine systems where they are located) (Hopkins and others, 1995; Samocha and others, 2004).

Some tropical and subtropical insects reach their northern distribution in the LRGV, such as the *Brachygastra mellifica* (Mexican honey wasp), which lives in colonies of tens of thousands, often constructed in riparian areas but also urban areas (Sugden and McAllen, 1994). Six of the 13 insects of highest conservation priority to Federal and State agencies, and now historically extirpated in the LRGV, are tiger beetles: 5 species in the genus *Cicindela*, with 1 likely extinct throughout its distribution, and 1 species of *Tetracha* (table 6). No recently published information was found on the ecologies of these species in the LRGV. Tiger beetles in the family Cicindelidae are globally distributed, and of the 120 species in the United States, 50 are endemic. Cicindelidae is a globally distributed and diverse family of insects and can have important value in conservation planning, even at small spatial scales (Cassola and Pearson, 2000). For example, many species of tiger beetles have strict ecological requirements, often with high habitat specificity during some part of their life cycle and therefore are good indicators of ecological threats (Cassola and Pearson, 2000). Reassessment of their status in the LRGV could provide broad landscape-level planning.

Table 6. Endangered and rare invertebrate and vertebrate species found in the four-county area of the Lower Rio Grande Valley in southern Texas, from the Annotated County Lists of Rare Species by the Texas Parks and Wildlife Department (2014), NatureServe (2013), and U.S. Fish and Wildlife Service Federal listings.

[Federally or State listed as E, endangered; T, threatened; C, candidate species; R, rare in Texas but with no regulatory status. NatureServe's G1 or S1, critically imperiled globally or subnationally, in this case Texas; G2 or S2, imperiled and very vulnerable; G3 or S3, vulnerable; G4 or S4, apparently secure; G5 or S5, secure; T, infraspecific classifications that follow the same status as G and S; GH, SH, or H, historical occurrence/possibly extinct or extirpated; SX, presumed extirpated/extinct; B, breeding]

Species	Listing		Rank		County occurrence
	Federal	State	Global	State	
Invertebrates–mussels					
Fusconaia mitchelli (false spike mussel)		T	GH	SH	Cameron (H), Hidalgo (H), Starr (H)
Popenaias popeii (Texas hornshell)	C	T	G1	S1	Hidalgo (H), Starr (H)
Potamilus metnecktayi (Salina mucket)		T	G1	S1	Cameron, Hidalgo, Starr
Invertebrates–insects					
Agapema galbina (Tamaulipan agapema)		R	G1	SH	Cameron, Hidalgo
Calephelis rawsoni (Rawson's metalmark)		R	G4	SNR	Willacy
Campsurus decoloratus (mayfly)		R	G3	SNR	Hidalgo
Cicindela cazieri (Cazier's tiger beetle)		R	G2	S2	Starr
Cicindela nigrocoerulea subtropica (subtropical black sky tiger beetle)		R	G5T2	SH	Cameron (H)
Cicindela obsoleta neojuvenilis (neojuvenile tiger beetle)		R	G5T1	SH	Hidalgo (H), Starr (H)
Ellipsoptera nevadica olmosa (Los Olmos tiger beetle)		R	G5T2	S1S2	Hidalgo, Willacy
Eximacris superbum (superb grasshopper)		R	G5	SH	Willacy (H)
Opilidia chlorocephala smythi (Smyth's tiger beetle)		R	GUTH	SX	Cameron (H)
Rhionaeschna dugesi (arroyo darner)		R	G4	SNR	Hidalgo
Sphingicampa blanchardi (royal moth)		R	G1	SNR	Cameron, Hidalgo
Stallingsia maculosus (Manfreda giant-skipper)		R	G1	S1	Cameron, Hidalgo
Tetracha affinis angustata (upland big-headed tiger beetle)		R	G5T4	SNR	Hidalgo, Starr, Willacy
Amphibians					
Hypopachus variolosus (sheep frog)		T	G5	S2	Cameron, Hidalgo, Starr, Willacy
Leptodactylus fragilis (Mexican white-lipped frog)		T	G5	S1	Cameron, Hidalgo, Starr
Notophthalmus meridionalis (black-spotted newt)		T	G1	S1	Cameron, Hidalgo, Starr, Willacy
Rhinophrynus dorsalis (Mexican burrowing toad)		T	G5	S2	Starr
Siren sp. (South Texas siren, large Rio Grande form)		T	GNRQ	SNR	Cameron, Hidalgo, Starr, Willacy
Smilisca baudinii (Mexican treefrog)		T	G5	S3	Cameron, Hidalgo, Starr, Willacy
Fishes					
Anguilla rostrata (American eel)		R	G4	S5	Cameron, Hidalgo, Willacy
Awaous banana (river goby)		T	G5	S1	Cameron
Ctenogobius claytonii (Mexican goby)		T	GNR	S1	Cameron, Hidalgo
Hybognathus amarus (Rio Grande silvery minnow)	E	E	G1	SX	Cameron (H), Hidalgo (H), Starr (H)
Microphis brachyurus (opossum pipefish)		T	G4G5	S1	Cameron, Willacy
Notropis jemezanus (Rio Grande shiner)		R	G3	S3	Cameron, Hidalgo, Starr
Pristis pectinata (smalltooth sawfish)	E	E	G1G3	SNR	Cameron, Willacy

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Species	Listing		Rank		County occurrence
	Federal	State	Global	State	
Reptiles					
Caretta caretta (loggerhead)	T	T	G3	S2	Cameron, Willacy
Cemophora coccinea lineri (Texas scarlet snake)		T	G5T2	S2	Cameron, Willacy
Chelonia mydas (green turtle)	T	T	G3	S1	Cameron, Willacy
Coniophanes imperialis (black-striped snake)		T	G4G5	S2	Cameron, Hidalgo, Willacy
Crotaphytus reticulatus (reticulate collared lizard)		T	G3	S2	Hidalgo, Starr
Dermochelys coriacea (leatherback)	E	E	G2	S1	Cameron, Willacy
Drymarchon melanurus erebennus (Texas indigo snake)		T	G5T4	S3	Hidalgo, Starr, Willacy
Drymobius margaritiferus (speckled racer)		T	G5	S1	Cameron, Hidalgo, Willacy
Eretmochelys imbricata (Atlantic Hawksbill)	E	E	G3T3	S1	Cameron, Willacy
Gopherus berlandieri (Texas tortoise)		T	G4	S3	Cameron, Hidalgo, Starr, Willacy
Holbrookia lacerata (spot-tailed earless lizard)		R	G3	S3?	Hidalgo, Starr, Willacy
Holbrookia propinqua (keeled earless lizard)		R	G4	S3?	Cameron, Willacy
Lepidochelys kempii (Kemp's ridley)	E	E	G1	S1	Cameron, Willacy
Leptodeira septentrionalis septentrionalis (northern cat-eyed snake)		T	G5	S2	Cameron, Hidalgo, Starr, Willacy
Phrynosoma cornutum (Texas horned lizard)		T	G4G5	S4	Cameron, Hidalgo, Starr, Willacy
Birds					
Anthus spragueii (Sprague's pipit)	C	R	G4	S2	Cameron, Hidalgo, Starr, Willacy
Athene cunicularia hypugaea (western burrowing owl)		R	G4T4	S2B	Cameron, Willacy
Buteo albicaudatus (white-tailed hawk)		T	G4G5	S4	Cameron, Hidalgo, Starr, Willacy
Buteo albonotatus (zone-tailed hawk)		T	G4	S3	Cameron, Hidalgo, Starr, Willacy
Buteo nitidus plagiatus (gray hawk)		T	GNR	S2	Cameron, Hidalgo, Starr
Buteogallus anthracinus (common black-hawk)		T	G4G5	S2	Cameron, Hidalgo, Starr, Willacy
Calidris canutus rufa (rufa red knot)	T		G4T2		Cameron, Hidalgo
Camptostoma imberbe (northern beardless-tyrannulet)		T	G5	S3	Cameron, Hidalgo, Starr, Willacy
Charadrius nivosus (snowy plover)		R	G3	S3B	Cameron, Hidalgo, Willacy
Charadrius melodus (piping plover)	T	T	G3	S2	Cameron, Willacy
Charadrius montanus (mountain plover)		R	G3	S2	Hidalgo
Chondrohierax uncinatus (hook-billed kite)		R	G4	S2	Hidalgo, Starr
Egretta rufescens (reddish egret)		T	G4	S3	Cameron, Hidalgo, Willacy
Falco femoralis septentrionalis (northern aplomado falcon)	E	E	G4T2	S1	Cameron, Hidalgo, Willacy
Falco peregrinus (peregrine falcon)		T	G4	S3	Cameron, Hidalgo, Starr, Willacy

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Species	Listing		Rank		County occurrence
	Federal	State	Global	State	
Birds—Continued					
Geothlypis trichas insperata (Brownsville common yellowthroat)		R	G5T2	S1B	Cameron, Hidalgo, Starr
Glaucidium brasilianum cactorum (cactus ferruginous pygmy-owl)		T	G5T3	S3	Cameron, Hidalgo, Starr, Willacy
Icterus cucullatus cucullatus (Mexican hooded oriole)		R	G5	S4B	Starr
Icterus cucullatus sennetti (Sennet's hooded oriole)		R	G5	S3B	Cameron, Willacy
Icterus graduacauda audubonii (Audubon's oriole)		R	G5T4	S3B	Cameron, Hidalgo, Starr, Willacy
Mycteria americana (wood stork)		T	G4	SH	Cameron (H), Hidalgo, Starr, Willacy
Numenius borealis (Eskimo curlew)	E	E	GH	SH	Cameron (H), Willacy (H)
Onychoprion fuscatus (sooty tern)		T	G5	S2	Cameron, Willacy
Pachyramphus aglaiae (rose-throated becard)		T	G4		Cameron, Hidalgo, Starr, Willacy
Parula pitiayumi (tropical parula)		T	G5	S3	Cameron, Hidalgo, Starr, Willacy
Peucaea botterii texana (Texas Botteri's sparrow)		T	G4T4	S3	Cameron, Hidalgo, Willacy
Plegadis chihi (white-faced ibis)		T	G5	S4	Cameron, Hidalgo, Willacy
Psilorhinus morio (brown jay)		R	G5	S2B	Starr
Sternula antillarum athalassos (interior least tern)	E	E	G4T2	S2S3	Hidalgo, Starr
Mammals					
Choeronycteris mexicana (Mexican long-tongued bat)		R	G4	S1	Cameron, Hidalgo, Starr, Willacy
Lasiurus ega (southern yellow bat)		T	G5	S1	Hidalgo, Willacy
Leopardus pardalis albescens (northern ocelot)	E	E	G4	S1	Cameron, Hidalgo, Starr, Willacy
Mormoops megalophylla (Peter's ghost-faced bat)		R	G4	S2	Cameron, Hidalgo, Starr, Willacy
Myotis velifer (cave myotis)		R	G5	S4	Hidalgo, Starr
Myotis yumanensis (Yuma myotis)		R	G5	S4	Starr
Nasua narica (white-nosed coati)		T	G5	S2?	Cameron, Hidalgo, Starr, Willacy
Oryzomys couesi (Coues' rice rat)		T	G5T2/4	S2	Cameron, Hidalgo, Starr, Willacy
Panthera onca (jaguar)	E	E	G3	SH	Cameron (H), Willacy (H)
Puma yagouaroundi cacomitli (Gulf Coast jaguarundi)	E	E	G4T3	S1	Cameron, Hidalgo, Starr, Willacy
Spilogale putorius interrupta (Plains spotted skunk)		R	G4T4	S3	Cameron, Hidalgo, Starr, Willacy
Trichechus manatus (West Indian manatee)	E	E	G2		Cameron, Willacy

The LRGV is considered one of the most species-rich butterfly areas in the United States (Wauer, 2004; table 7). Diversity of butterflies is typically greatest in neotropical areas (Robbins and Opler, 1997), and many neotropical butterflies find their way northward into the LRGV (fig. 9). The larval caterpillar stages of many lepidopterans are agricultural pests and targets of pesticides, which could be harmful to reptiles and birds that rely on them for food—a potentially pernicious impact little studied in the LRGV. The South Texas Chapter of the North American Butterfly Association (2015) maintains a checklist of butterfly occurrences in the LRGV. More than 280 species of butterflies from at least 6 families and 20 subfamilies have been confirmed in the LRGV, and many other species are considered hypothetical and likely to be observed in the future (table 7). Notably, >50 percent of the recorded butterfly species are considered LRGV specialists, or species that rarely occur anywhere else in the United States.

Table 7. Numbers of species of butterflies in 6 families and 20 subfamilies found in Starr, Hidalgo, and Cameron Counties of south Texas from the North American Butterfly Association Checklist of Rio Grande Valley Butterflies (South Texas Chapter of the North American Butterfly Association, 2015).

Family (common names)	Subfamily (common names)	Number of species confirmed	Number of species not seen elsewhere in the United States	Number of species not found north of the Lower Rio Grande Valley
Papilionidae (Swallowtails)	Papilioninae (Swallowtails)	14	10	5
Pieridae (Whites and Sulphurs)	Pierinae (Whites)	9	6	3
	Coliadinae (Sulfurs)	20	7	1
	Dismorphiinae (Mimic-Whites)	1	1	1
Lycaenidae (Gossamar-wing)	Theclinae (Hairstreaks)	32	24	15
	Polyommatinae (Blues)	7	0	0
Riodinidae (Metalmarks)	Riodinae (Metalmarks)	10	7	6
Nymphalidae (Brushfooted)	Libytheinae (Snouts)	1	0	0
	Heliconiinae (Heliconians and Fritillaries)	9	0	0
	Nymphalinae (True Brushfoots)	30	11	2
	Limenitidinae (Admirals)	19	18	7
	Charaxinae (Leafwings)	6	3	2
	Apaturinae (Emperors)	5	2	1
	Satyrinae (Satyrs)	2	0	0
	Danainae (Clearwings)	4	4	4
	Danainae (Monarchs)	4	0	0
Hesperiidae (Skippers)	Heteropterinae (Skipperlings)	1	1	1
	Pyrginae (Spread-wing Skippers)	72	50	31
	Hesperiinae (Grass-Skippers)	36	19	12
	Hesperiinae (Giant Skippers)	2	0	0
Totals		**283**	**163**	**91**

Figure 9. Diversity of butterflies in the Lower Rio Grande Valley, which is unparalleled with nearly 300 confirmed species, of which 163 are generally not found elsewhere in the United States. Striking representatives are *A*, *Heliconius charithonia* (zebra heliconian); *B*, *Agraulis vanillae* (Gulf fritillary); *C*, *Chlosyne janais* (crimson patch); *D*, *Papilio polyxenes* (black swallowtail butterfly); *E*, *Lasaia sula* (blue metalmark); and *F*, *Diaethria anna* (Anna's eighty-eight). ©Larry Ditto Nature Photography, used with permission.

Amphibians and Reptiles

Although six amphibians in the LRGV are listed as State threatened (table 6), only the relatively common *Rana berlandieri* (Rio Grande leopard frog—Parker and Goldstein, 2004) and the large *Siren* sp. (South Texas siren—LaFortune, 2015) have received limited research attention since the late 1980s. Summer and autumn diets of Rio Grande leopard frogs from Santa Ana NWR, various tracts in the Lower Rio Grande Valley NWR, and a private ranch in Willacy County were dominated by grasshoppers, beetles, moths, and butterflies. Notably, frogs shifted their diets with the autumn emergence of *Spodoptera frugiperda* (fall armyworms), which composed 78 percent of their diets at the ranch and 90.4 percent at Santa Ana NWR. Fall armyworms are agricultural pests in the LRGV (Raulston and others, 1990, 1992; Wolf and others, 1995; see "Pesticides" section of this report), and pesticides used to control them could negatively affect the Rio Grande leopard frog. Recent work on sirens in southern Texas suggests that the large form in the LRGV may be genetically distinct enough from *Siren lacertina* (greater siren) and *S. intermedia* (lesser siren) to warrant recognition as a separate species (LaFortune, 2015). Overall, lack of information on amphibians in the LRGV limits understanding of their conservation needs.

Ten species of reptiles (5 snakes, 2 lizards, 2 sea turtles, and 1 tortoise) in the LRGV are considered State threatened, and 2 lizard species are considered rare, with a majority occurring in Cameron and Willacy Counties (table 6). The State-threatened *Gopherus berlandieri* (Texas tortoise; fig. 4*E*) prefers semidesert shrubland, and its population ecology and reproductive biology have been studied in Cameron County (Bury and Smith, 1986; Rose and Judd, 1989, 1991, 2014; Judd and Rose, 2000), where it occurs on nearly all tracts in the Lower Rio Grande Valley NWR and Laguna Atascosa NWR (Bury and Smith, 1986). Current threats include habitat loss to agriculture and urbanization, resulting in a highly fragmented distribution; potential conflicts with grazing interests; capture as pets or for the pet trade; need for better enforcement of its protected status; and lack of a conservation plan outlining recovery objectives by local, State, and Federal agencies (e.g., Rose and Judd, 2014). Studies north of the LRGV demonstrated that Texas tortoises can use a variety of shrub-dominated habitats but avoid extremes in canopy cover, riparian areas, and old fields; furthermore, common range-management practices (e.g., mechanical brush clearing and root plowing) create unusable habitats for Texas tortoises (Kazmaier, Hellgren, and Ruthven, 2001; Kazmaier, Hellgren, and Synatzske, 2001; Kazimaier, Hellgren, Synatzske, and Ritledge, 2001).

There are five federally listed species of sea turtles in 5 of the 6 living genera that occur in gulf waters, bays, lagoons, and channels east of the LRGV. Federally endangered sea turtles of the LRGV are Kemp's ridley, the most endangered of all sea turtles (National Marine Fisheries Service [NMFS], USFWS, and SEMARNAT, 2011); *Eretmochelys imbricata* (hawksbill—NMFS and USFWS, 1993); and *Dermochelys coriacea* (leatherback—NMFS and USFWS, 1992). Threatened species are *Caretta caretta* (loggerhead—Plotkin and others, 1993; NMFS and USFWS, 2008) and *Chelonia mydas* (green sea turtle—NMFS and USFWS, 1991). All five species have been listed since the 1970s. Recovery plans for all sea turtles highlight nest-site destruction, overharvest, ingestion of oceanic human debris, and mortality in fishing nets (e.g., shrimp trawls) as principal causes of endangerment (Smith and Childs, 2002). Mandatory turtle excluder devices in shrimp trawls have greatly reduced this cause of mortality (Lewiston and others, 2003).

Sea turtles nest on beaches of Texas, principally on Padre Island National Seashore, South Padre Island, and Boca Chica tract in the Lower Rio Grande Valley NWR (fig. 10). Recent nesting records from the Kemp's Ridley Sea Turtle Recovery Project on South Padre Island (Cameron and Willacy Counties of the LRGV) show that Kemp's ridleys are the most common nesters, with 57 nests documented in 2012; 105 additional nests were found just north in Padre Island National Seashore. Nesting records of the other species of sea turtles in southern Texas are considerably lower: 13 or fewer loggerhead nests per year, 15 green sea turtle nests per year, 1 hawksbill nest, and 1 leatherback nest. The most abundant sea turtles in Gulf of Mexico waters off the southern Texas coast are green turtles, Kemp's ridleys, and loggerheads, and the least abundant are hawksbills (perhaps mostly pelagic stage juveniles from Yucatan nesting areas—Amos, 1989; Bowen and others, 2007) and leatherbacks (only two strandings off Cameron County in 1969 and 1990—Judd and others, 1991); green turtles vastly outnumber other sea turtle species in southern Texas inshore waters (Caillouet and others, 1991; Shaver, 2000; D.J. Shaver, written commun.).

Pioneering work on Kemp's ridley by D.J. Shaver and her colleagues under cooperative agreements with the governments of Texas, Mexico, and the United States began in 1978. Prior to that, the only major nesting site of Kemp's ridleys was a 26-km stretch of beach at Rancho Nuevo, Mexico; sporadic nesting near Corpus Christi, Tex., was known (Shaver, 1992; Smith and Childs, 2002). A head-start program began in 1978; eggs were collected at Rancho Nuevo, hatched at a facility at Padre Island National Seashore, reared to 6–11 months of age at the National Marine Fisheries Lab in Galveston, Tex., and released (e.g., Caillouet and others, 1995; Shaver, 1991, 1992, 1996; Shaver and Caillouet, 1998). Numbers of nests of Kemp's ridleys on the Texas coast have steadily increased from nine in 1996 to a peak of 209 in 2012, decreasing to 119 in 2014 (National Park Service, 2013).

The Lower Laguna Madre provides critical habitat for juvenile green turtles; only very occasionally are hawksbill, Kemp's ridley, or loggerhead turtles found there (D.J. Shaver, written commun.). Although created by humans to provide access from the Gulf of Mexico into the Lower Laguna Madre, Port Mansfield Channel and Brazos Santiago Pass provide young turtles with foraging and resting opportunities and access to the Lower Laguna Madre (Renaud and others, 1995; Shaver, 1994; Shaver and others, 2013). Recent sighting

Figure 10. An endangered *Lepidochelys kempii* (Kemp's ridley) nesting on South Padre Island. Photograph courtesy of the National Park Service.

frequencies of green turtles near jetties at Brazos Santiago Pass in 2009 suggest that recruitment of juveniles has increased nine times since comparable sightings in 1992–93 and that the lower Texas coast is an important "developmental foraging area" for juvenile green turtles (Metz and Landry, 2013, p. 293).

Fishes

Seven species of fishes (4 freshwater, 2 marine, and 1 anadromous), part of or historically part of the LRGV fauna, are considered endangered, threatened, or rare by Federal and State agencies (table 6). The Federal- and State-endangered freshwater Rio Grande silvery minnow (Bestgen and Platania, 1991; Hubbs and others, 2008; USFWS, 2010b) and the marine *Pristis pectinata* (smalltooth sawfish—NMFS, 2009) are effectively extirpated in areas associated with the LRGV. The Rio Grande silvery minnow was described taxonomically from a collection near Brownsville, Tex., but it has not been collected anywhere below Falcon Dam since 1961. The likely extinct *Notropis orca* (phantom shiner) once occurred at Boca Chica Beach in the mouth of the Rio Grande near Boca Chica Beach into New Mexico, but it was last collected from the Mexican side of the lower Rio Grande in 1975 (Miller and others, 1989).

Historically, the freshwater fish assemblage in the lower Rio Grande has been remarkable, with 142 species in 49 families (e.g., Contreras-Balderas and others, 2002; Hubbs and others, 2008). Striking changes in the fish community of the lower Rio Grande involve a shift of freshwater forms retreating upstream (as many as 32 species) and their replacement with marine and estuarine forms (as many as 54 species), resulting from increased salinity, turbidity, temperatures, and pollution and decreased freshwater flows into the lower reaches of the Rio Grande (Treviño Robinson, 1959; Edwards and Contreras-Balderas, 1991; Contreras-Balderas and Lozano-Vilano, 1994; Anderson and others, 1995; Contreras-Balderas and others, 2002; Mathis, 2005). The community now includes four exotics: *Oreochromis aureus* (Nile tilapia—Edwards and Wood, 1991; Martin and others, 2010), *Morone chrysops* (white bass), *Carassius* *auratus* (freshwater goldfish), and *Cyprinus carpio* (common carp—Contreras-Balderas and others, 2002).

Typically, fish communities in enclosed hypersaline lagoons are characterized by low diversity and big swings in abundance, dependent on heavy rainfall and “hurricane-opened passes” that together lower a lagoon’s salinity and allow surges in productivity (Tunnell, 2002a, 2002b; Withers and Dilworth, 2002, p. 223). Densities and biomasses of fishes and decapods are high in healthy seagrass meadows and fundamental to high coastal productivity (Sheridan and Minello, 2003). Now (2016), the hypersaline character of Laguna Madre has been reduced—perhaps more so in the Upper Laguna Madre—by construction of permanent passages such as the Gulf Intracoastal Waterway and Port Mansfield Channel (e.g., Tunnell, 2002d), generally altering fish diversity. Based on limited research comparing fish communities in the Upper and Lower Laguna Madre, overall numbers of species are similar, but two families are apparently unique to the Lower Laguna Madre: Chaetodontidae (butterflyfishes) and Pomacentridae (damselfishes—Withers and Dilworth, 2002).

The estuarine-dependent marine fishes *Sciaenops ocellatus* (red drum), *Cynoscion nebulosus* (spotted sea trout), and *Pogonias cromis* (black drum) are the most sought after by anglers east of the LRGV (McKee, 2008). Past depleted stocks of commercially harvested red drum (Withers and Dilworth, 2002; Carson and others, 2013) and recent genetic research (Rooker and others, 2010) highlight the need to identify and conserve unique subpopulations of many organisms. Based on analyses of isotopic carbon and oxygen in otoliths (fish ear bones), stocks of red drum along the Texas coast can be differentiated into regional nurseries of origin, with Laguna Madre being 1 of 4 uniquely identifiable natal areas; natal homing for subsequent reproduction also highlights the importance of “spatially explicit management” of red drum to perpetuate its ecological and genetic diversity (Rooker and others, 2010, p. 195).

Birds

Thirty-four percent of all invertebrate and vertebrate species of conservation concern to Federal and State agencies in the LRGV are birds (table 6). The 29 species include 5 Federal- and State-threatened or endangered species, 14 State-threatened species, and 10 rare species listed as of concern by the State of Texas. The riparian zone of the Rio Grande once harbored a lush forest, apart from the more upland and extensive areas of thornscrub and grasslands. These characteristics made the LRGV and associated Laguna Madre important stopovers for avian migrants traveling between wintering areas in the Neotropics and breeding areas farther north in the United States and Canada (Brush, 2005; Mehlman and others, 2005; Ruth and others, 2008). The Central Flyway converges in the LRGV, and some bird species are funneled through it from the Mississippi Flyway along the Texas coast, resulting in the tremendous diversity of birds that breed and winter in and migrate through the LRGV (Brush, 2005).

Only 2–5 percent of the native habitat remained in most of the LRGV by the late 1980s. Nevertheless, the great and ever-changing variety of abiotic and biotic conditions and resulting habitats in the LRGV—even those caused by human activities—result in the richest bird community in the United States, a mix of more than 400 species (Brush, 2008a) and one of the top 10 destinations for bird watchers (Gehlbach, 1987; Brush, 2005). Birds symbolic of the LRGV and near neighboring lands, with common names as unique or colorful as they are, include the northern aplomado falcon, *Cyanocorax yncas* (green jay—Gayou, 1986), *Ortalis vetula* (plain chachalaca—Peterson, 2000), and *Pitangus sulphuratus* (great kiskadee—Brush, 1993, 2005; Brush and Fitzpatrick, 2002).

Many bird species in the LRGV are specialists in remnant habitat types that have experienced the greatest loss. Especially affected are birds that specialize on mature riparian forests such as the *Leptotila verreauxi angelica* (white-tipped dove), which has declined significantly in the LRGV (Flood and others, 2002; Brush, 2005; Rupert and Brush, 2006; Breeden and others, 2009; Brush and Feria, 2015). Similar changes are occurring southward in Mexico, where tropical species are moving north and temperate species are moving south (Brush, 2009a). These changes in the avian community of the LRGV are likely a result of complex interactions of human-caused, localized habitat changes and very large-scale effects such as climate change (Brush, 2005, 2008a; Rupert and Brush, 2006; Rappole and others, 2007). The following sections provide syntheses of important avian resources in the LRGV, with the substantial, supportive LRGV-centric research conducted on them since the late 1980s (appendix *B*). Little or no supportive research has been conducted on some taxonomic groups; for example, richness of raptors in the LRGV is high (Brush, 2005) and includes species of concern in the United States such the *Buteo nitidus plagiatus* (gray hawk), *B. albicaudatus* (white-tailed hawk), and *Chondrohierax uncinatus* (hook-billed kite) (table 6). Nevertheless, aside from the northern aplomado falcon and the peregrine falcon, no studies have been undertaken on other raptor species in the LRGV.

Northern Aplomado Falcon

One of three subspecies of the wide-ranging aplomado falcon, the federally endangered northern aplomado falcon (fig. 11), occurs in the LRGV. It is a rare, resident, medium-sized, and slender neotropical raptor, generally inhabiting open habitats (USFWS, 2014b). Its historical distribution in the United States encompassed borderlands from southern and west-central Texas to Arizona (Keddy-Hector 1990, 2000; Perez and others, 1996; Truett, 2002; Brush, 2005). Early reports from the LRGV suggested that the northern aplomado falcon was relatively common in eastern Willacy and Cameron Counties (Brush, 2005), particularly in coastal grasslands between Brownsville and Port Isabel, Tex., with

Figure 11. The endangered *Falco femoralis septentrionalis* (northern aplomado falcon). More than 800 northern aplomado falcons have been successfully reintroduced in the Lower Rio Grande Valley, with 16–18 nesting pairs now found each year. ©Larry Ditto Nature Photography, used with permission.

scattered woody vegetation such as mesquite and yuccas (Perez and others, 1996). This area, known as the Palo Alto Prairie, seems to have been the principal location for breeding northern aplomado falcons in the LRGV, but they also occurred northward along the Texas coast to the King Ranch in Kleberg County (Keddy-Hector, 2000).

The northern aplomado falcon was listed as endangered in the United States in 1986 (Keddy-Hector, 1990, 2000; Perez and others, 1996). Years of habitat loss and degradation from overgrazing of coastal grasslands and savannas, resulting in woody brush encroachment (initially mostly by sheep—Thompson, 1997; Truett, 2002; Brush, 2005), and probably overcollection of skins and eggs from 1890 through 1910 (Hector, 1987; USFWS, 2014b) effectively extirpated the northern aplomado falcon from the LRGV as early as the 1930s (Perez and others, 1996; Truett, 2002; Jenny and others, 2004; Brush, 2005). Although there were sporadic sightings of northern aplomado falcons, indicating at least ephemeral presence in the coming decades, they did not breed again in the United States until captive breeding and reintroduction efforts began in the 1980s (Perez and others,1996; Jenny and others, 2004).

Because early studies of the northern aplomado falcon were limited, our understanding of its ecology in the LRGV is tied to efforts to reintroduce it and follow up on newly established individuals (Perez and others, 1996; Brown and others, 2003, 2006; Jenny and others, 2004; Brown and Callopy, 2008, 2012), supplemented with information from Mexico (Keddy-Hector, 2000). Habitat types used by northern aplomado falcons in the LRGV and Mexico include coastal prairies, particularly those with scattered yuccas and mesquites (Perez and others, 1996), oak woodlands, and riparian forests amidst desert grasslands; in other parts of their distribution farther south, they occur in coastal savannas, marshlands, and even cut-over pasturelands (Keddy-Hector, 2000).

As of 2004, in partnership with The Peregrine Fund, more than 800 northern aplomado falcons were released in the LRGV, with 16–20 nesting pairs now found each year; the recovery plan's goal of 60 breeding pairs in the United States includes 30–35 pairs in the LRGV (Keddy-Hector, 2000; USFWS, 2014a). Northern aplomado falcons are now found in and around Laguna Atascosa NWR and the easternmost tracts of the Lower Rio Grande Valley NWR. Some concern has been expressed about quality of available nesting habitat; some pairs might be using poor-quality nest sites, suggesting a shortage of suitable nest sites in the LRGV relative to current population size (Brown and Callopy, 2008, 2012). Addled eggs of northern aplomado falcons in the LRGV have been regularly assessed for contaminants, which have generally been found in background levels, but mercury (Hg) levels appear to be elevated (Mora and others, 1997, 2008, 2011).

Orioles

Five of the nine North American orioles occur in the LRGV (Brush, 2005), and two of them, *Icterus graduacauda* (Audubon's oriole; fig. 12*B*) and *I. cucullatus cucullatus* and *I. c. sennetti* (both known as the hooded oriole), are considered rare in Texas (table 6). Loss or alteration of habitats by humans, drought, and periodic freezes (Lonard and Judd, 1991; Brush and Cantu, 1998; Flood and others, 2002; Rupert and Brush, 2006) and parasitism by range-expanding *Molothrus ater* (brown-headed cowbirds) and *M. aeneus* (bronzed cowbirds—Monk, 2003; Kostecke and others, 2004; Monk and Brush, 2007; Janecka and Brush, 2014) have affected oriole abundances in the LRGV. The bronzed cowbird has expanded northward and occurs in relatively high densities (3.25 cowbirds per hectare [1.32 cowbirds per acre]) in the LRGV, often most closely associated with agricultural areas (Carter, 1986; Warren, 2002). Cowbirds are known to negatively affect nest success of *I. gularis* (Altamira orioles—Brush, 2005; fig. 12*A*), Audubon's orioles (Monk and Brush, 2007), and hooded orioles (Brush, 2000c) in the LRGV. They also parasitize nests of green jays (fig. 12*E*), *Toxostoma longirostre* (long-billed thrashers), *Cardinalis cardinalis* (northern cardinals), and *Arremonops rufivirgatus* (olive sparrows—Brush, 1998b; T. Brush, written commun.) and rarely nests of *Coccyzus americanus* (yellow-billed cuckoos—Clotfleter and Brush, 1995), *Tyrannus verticalis* (western kingbirds), and *Tyrannus couchii* (Couch's kingbirds—Brush, 1999b).

Audubon's orioles have disappeared from large parts of the LRGV (Sennett, 1879; Brush, 2000d; Flood and others, 2002; Monk and Brush, 2007; Brush and Feria, 2015). They now occur only in the western and northern parts of the LRGV in areas less fragmented by agriculture and urbanization, and they have disappeared from central and eastern parts of the LRGV where they were once found along the Rio Grande (Flood and others, 2002; Brush, 2005). Audubon's orioles do reasonably well in second-growth conditions in Mexico, so they may persist in the LRGV if they acclimate to changing second-growth habitats (Flood and others, 2002). Given their high vulnerability to brood parasitism, it is thought that parasitism by bronzed and brown-headed cowbirds is the main negative factor affecting their populations. Similarly, hooded orioles were once the most abundant oriole species in the LRGV but have declined greatly, now occurring as an uncommon breeder in urban areas (Brush, 2005). Hooded orioles are no longer common in riparian areas of the LRGV but still occur in and near Santa Ana NWR. They are known to forage in agricultural areas, which could expose them to pesticides (Brush, 2005), and they are very susceptible to cowbird parasitism (Brush, 2000c).

Among the other oriole species in the LRGV, the Altamira oriole—noted for its long, pendulous nest (Brush, 1998c; fig. 12*A*)—was not found during the earliest bird surveys in the LRGV (Sennett, 1879; Brush, 2005). It spread through much of the LRGV in the 1950s and quickly became the most common oriole (Brush, 1998c, 2005; Brush and Pleasants, 2005). The increase in Altamira orioles in the LRGV coincided with declines in other sympatric oriole species, but since the 1980s, Altamira orioles have steadily declined in the LRGV (Brush, 1998c; Hathcock and Brush, 2004). *Icterus spurius* (Orchard orioles) once bred in the LRGV but have retreated northward perhaps because of parasitism from cowbirds and interspecific interactions with other species of orioles (Brush, 2005, 2008a). *I. bullockii* (Bullock's orioles) are an arid-land species, most common in the western United States. In the LRGV, they once bred in downstream areas of Hidalgo County (last occurrence in 1996) but are now restricted to less fragmented areas in Starr County and above Falcon Dam (Brush, 2005).

Other Riparian Dependents

Several bird species are at particular risk of extirpation or continued rarity in their limited United States distributions, particularly in the LRGV (e.g., Brush, 2005; Brush and Feria, 2015). Among those species, *Camptostoma imberbe* (northern beardless-tyrannulet) is a small flycatcher that only occurs in the United States in extreme southern Texas and a similarly small area of southern Arizona. In the LRGV, it has lost much of its preferred riparian forest habitat, but some evidence suggests that it tolerates second-growth habitats. Nevertheless, northern beardless-tyrannulets could benefit from management that favors revegetation of large riparian trees that support epiphytic mosses preferred for nesting (Brush, 1999a, 2005), particularly cedar elm where 93 percent of 28 nests were found in a recent study (Werner, 2004; Werner and others, 2015). Other forest species similarly affected by loss of riparian forests along the Rio Grande, and are now rare as a result, include *Pachyramphus aglaiae* (rose-throated becard—Howell and Webb, 1995; Brush, 2000a, 2005; Miller and others, 2015) and *Parula pitiayumi* (tropical parula), which also prefer epiphytic mosses in tall trees for nesting (Regelski and Moldenhauer, 1997; Brush, 1999a). In recent years, the few nesting attempts of rose-throated becards have only been seen in Anzalduas Park and Santa Ana NWR in Hidalgo County, but these attempts were unsuccessful (T. Brush, written commun.).

In the United States, the *Amazilia yucatanensis* (buff-bellied hummingbird) breeds only in the LRGV, primarily in Hidalgo and Cameron Counties, and seems to prefer scrubby and broken forests along and near the Rio Grande (Brush, 2005; fig. 12*C*). Its distribution is relatively restricted for a hummingbird, from southern Texas along the Gulf Coast of

Figure 12. Prominent species of birds found in the Lower Rio Grande Valley (LRGV). With more than 420 species of birds documented in the LRGV, riparian forest and brushland species have high conservation value. *A*, the iconic *Icterus gularis* (Altamira oriole); *B*, *I. graduacauda* (Audubon's oriole); *C*, *Amazilia yucatanensis* (buff-bellied hummingbird); *D*, *Ortalis vetula* (plain chachalaca); and *E*, *Cyanocorax yncas* (green jay). ©Larry Ditto Nature Photography, used with permission.

Mexico into the Yucatán in Mexico, Guatemala, and Belize; it is unique among North American hummingbirds because it regularly moves north in autumn and winters in low numbers in much of the southeastern United States (Chavez-Ramirez and Moreno-Valdez, 1999). Clearing of thornscrub and brushy habitats in the LRGV was probably detrimental to buff-bellied hummingbirds (Chavez-Ramirez and Moreno-Valdez, 1999; Brush, 2005). It appears to use residential and park areas in the LRGV and is more common in southern Texas than it once was (Brush, 2005).

Doves and Pigeons

Species richness of doves and pigeons in the relatively small LRGV is hard to match elsewhere in United States. Six native species (two exotic species are discussed under "Exotic or naturalized birds") are common to scarce, and three of them readily acclimate to human-altered agricultural and urban landscapes (e.g., Brush, 2005, 2008b; Collins and others, 2010). In the United States, *Patagioenas flavirostris* (red-billed pigeon—Lowther, 2002; fig. 13*C*) occurs only in the LRGV (fig. 13), and it was formerly widespread in relatively large numbers at mid-valley locations like Santa Ana NWR, nesting in riparian forests (Brush, 1998a, 2005, 2008a; Brush and Feria, 2015). Loss of riparian woodland and native brush and changes in the flood regime of the Rio Grande have greatly reduced preferred habitat of red-billed pigeons (Breeden and others, 2009). As a result, they are currently restricted to remnant riparian woodland near Falcon Dam in Starr County, where they still breed in mature stands of Mexican ash, willow, and Texas ebony (Brush, 2005; Breeden and others, 2009).

Among urban-shy and increasingly uncommon species, the white-tipped dove is secretive and relatively sedentary (fig. 13*B*) and occurs in low densities throughout the LRGV (Boydstun and DeYoung, 1988). It is more selective of nesting habitat than most other doves and consistently prefers increasingly rare and isolated forests of Texas ebony, sugarberry, and cedar elm in the LRGV, although they have been known to nest in citrus groves and urban parks in the past (Boydstun and DeYoung, 1985, 1987, 1988; Hayslette and others, 2000; Brush, 2005). *Columbina passerina* (common ground doves) are found primarily in dry, rural mesquite savannas and grassland/thornscrub and have the fewest interactions with other doves and pigeons in the LRGV (Brush, 2005).

White-winged doves have retained their importance to sportsman in the LRGV (Jahrsdoerfer and Leslie, 1988; Swanson and Rappole, 1992; Hayslette and others, 1996, 2000; Small and others, 2004; fig. 13*A*). Along with congeneric *Zenaida macroura* (mourning doves), white-winged doves are comfortable in agricultural and urban settings and readily nest in available offerings (Collins and others, 2010). Numbers of white-winged doves in the LRGV have varied through time, influencing harvest regulations (Small and Waggerman, 1999; Hayslette and others, 2000; Brush, 2005). They were much more abundant in 1930s and declined after being forced to shift nesting from diminishing native thorn brushlands to expanding citrus orchards, which were severely damaged by freezes in 1951, 1962, and 1983 (Lonard and Judd, 1991; Swanson and Rappole, 1992) and more recently in 1989 and 2011. Heavy use of growing urban areas in and north of the LRGV have benefited populations of white-winged doves. *Columbina inca* (Inca doves) thrive in urban areas in the LRGV (Brush, 2008b).

Thornscrub Species

The United States breeding distribution of the *Passerina versicolor* (varied bunting) is limited and concentrated in the United States-Mexico borderland (Howell and Webb, 1995), typically occurring in arid thornscrub habitat (Ehrlich and others, 1988). It was once common in coastal thickets in Cameron County in the eastern LRGV but no longer occurs there (Brush, 2005). Varied buntings still occur locally in the western LRGV, particularly in Starr County. Reasons for their disappearance in the eastern LRGV and general decline elsewhere are not understood, but habitat fragmentation and destruction are likely causes (Brush, 2005).

The *Micrathene whitneyi* (elf owl) is the smallest owl species in North America. In the United States, it is concentrated along the Mexican border from Arizona into Texas (Ehrlich and others, 1988). It was first reported in the LRGV in the 19th century but then disappeared for more than 70 years (Brush, 2005). It now occurs in the western one-half of the LRGV, primarily from Bentsen Rio Grande Valley State Park in Starr County to Santa Ana NWR and in tracts of the Lower Rio Grande Valley NWR adjacent to Anzalduas Park (Gamel, 1997; Gamel and Brush, 2001; Brush, 2005). Elf owls need large snags for nesting and prefer open chaparral in Santa Ana NWR, which could theoretically support as many as 800 elf owls with each pair residing in about 1 ha (Gamel and Brush, 2001).

Waterfowl, Colonial Waterbirds, and Shorebirds/Seabirds

The LRGV and associated Laguna Madre are well known for supporting diverse assemblages of well-studied waterfowl (Smith, 2002a), colonial waterbirds (Smith, 2002b), and shorebirds/seabirds (Brush, 1995; Withers, 2002c) (appendix *B*). A great diversity of wetland habitats occurs in southern Texas to support these species: seagrass meadows, estuarine bays, coastal salt and brackish tidal marshes and flats, closed depression wetlands, freshwater ponds, inland saline lakes, resacas, small riparian streams, backwater areas of the highly human-modified Rio Grande flood plain, and even commercial rice fields. Associated terrestrial habitats are essential for resting, nesting, and, for some species, feeding. Numerous dredge and barrier islands in Laguna Madre support mixed nesting rookeries of colonial waterbirds and seabirds; species richness of these rookeries is high, ranging from a single species up to 20 species nesting at the same location in the Lower Laguna Madre—highest where human disturbance is

A

B *C* *D*

E

Figure 13. Wetland birds and doves, which are notably diverse and abundant in the Lower Rio Grande Valley. *A*, *Zenaida asiatica* (white-winged dove), an important game species; *B*, the growingly rare *Leptotila verreauxi* (white-tipped dove) and *C*, *Patagioenas flavirostris* (red-billed pigeon); *D*, *Dendrocygna autumnalis* (black-bellied whistling ducks); and *E*, wintering *Aythya americana* (redheads). ©Larry Ditto Nature Photography, used with permission.

the lowest (Smith, 2002b). The Lower Rio Grande Valley NWR, in partnership with various water districts and cooperative farmers, manages seven wetlands totaling 162.2 ha (401 acres), with five potentially manageable wetlands of 80.9 ha (200 acres), to benefit wetland-dependent species.

Conservation of wetlands in the LRGV and associated Laguna Madre is fundamental to maintaining rich avian assemblages. Tens of thousands wintering redheads (fig. 13*E*) depend on meadows of shoal grass, typically at depths of 12–30 cm (4.7–11.8 in.—Mitchell, 1992), in the highly saline Lower Laguna Madre, associated wetlands of Laguna Atascosa NWR, and coastal freshwater ponds (Mitchell and others, 1994; Woodin, 1994, 1996; Custer and others, 1997; Michot and others, 2006; Woodin and others, 2008). Redheads prefer ponds with greater than average depths and percentages of open water and lower than average salinities—conditions that vary depending on annual rainfall and availability of ponds; redheads stay closest to lagoons in wet years but must travel farther in dry years (Ballard and others, 2010). *Anas clypeata* (northern shovelers) have a similar dependence on two habitats, freshwater ponds and estuarine wetlands, in the LRGV (Tietje and Teer, 1996). Conservation of coastal wetlands, sometimes compromised by local ranching operations and naturally occurring dry periods, is essential to maintaining viable wintering habitat for redheads and other waterbirds.

Freshwater and marine wetlands in the LRGV host a variety of special waterbirds. Inland, 10 percent of the North American population of long-billed curlews winter at the saline East Lake. Unique and rarely seen waterfowl throughout the LRGV include *Nomonyx dominicus* (masked ducks—Anderson and Tacha, 1999), *Dendrocygna bicolor* (fulvous whistling ducks), *Anas fulvigula* (mottled ducks), and *Mergus serrator* (red-breasted mergansers—Rupert and Brush, 1996). In riverine areas of the western LRGV, the Mexican race of *A. platyrhynchus diazi* (mallard) and naturally occurring (versus [vs.] domestic escapees) *Cairina moschata* (Muscovy ducks—Brush and Eitniear, 2002) can be seen. The largest known colony of the nesting *Egretta rufescens* (reddish egrets) occurs north of Port Isabel and off the coasts of Willacy and Cameron Counties (Brush, 2005).

Important to the conservation of coastal and barrier-island habitats, four distinct zones of critical wintering habitat have been formally designated for the federally threatened piping plover (U.S. Department of Interior, Fish and Wildlife Service, 2009) along the entire length and width of Padre Island from the northern boundary of Padre Island National Seashore south to the mouth of the Rio Grande and considerable areas of the eastern shores of Willacy and Cameron Counties along the Lower Laguna Madre. Piping plovers show strong site fidelity to their wintering home ranges, which average about 12 km^2 (4.6 mi^2), and they are most dependent on algal flats in autumn (arrival) and spring (departure) and exposed sand flats in winter (K.L. Drake, 1999; K.R. Drake, 1999b; Drake and others, 2001). *Sterna hirundo* (common terns) were once regular breeders in the coastal Rio Grande Delta but are now rare or absent (Brush, 2008a).

Mammals

Of the 143 native mammal species and 12 introduced exotic mammal species in Texas, about 50 of them occur in the LRGV (e.g., Jones and Jones, 1992; Jones, 1993; Schmidly 2003, 2004), including south Padre Island (e.g., Goetze and others,1999; Jones and Frey, 2013). Twelve (14 percent) of the 85 invertebrate and vertebrate species of conservation concern to Federal and State agencies in the LRGV are mammals (table 6). Four of the 12 species are federally and State-endangered species, and 3 threatened species and 5 rare species are listed by the State of Texas.

Bats

The rich bat fauna of the LRGV includes 14 resident and (or) migratory species (Chapman and Chapman, 1990; Schmidly, 2004), or nearly 30 percent of the total number of bat species in the United States and 30 percent of the overall number of mammal species in the LRGV. Five of the 12 (42 percent) mammals of conservation concern in the LRGV are bats (table 6), and two species reach their northern distributional limits in the LRGV: *Choeronycteris mexicana* (Mexican long-tongued bat), listed as near threatened on the IUCN Red List (Arroyo-Cabrales and Perez, 2008), and *Lasiurus ega* (southern yellow bat). Aside from museum specimens collected over the past century (e.g., Chapman and Chapman, 1990), no information exists on the status of individual bat species in the LRGV.

Small Mammals

Information on small mammal communities in the LRGV is limited. Sternberg and Judd (2006) found that three habitat types in the LRGV (native thornscrub woodland, agricultural field replanted in 1995, and unaided secondary succession following termination of farming in 1985) supported up to 10 rodent species, typically 5–9, with very high overall densities of 269–388 rodents per hectare. *Sigmodon hispidus* (cotton rats), *Peromyscus leucopus* (white-footed mice), and *Liomys irroratus* (Mexican spiny pocket mice) were the most abundant rodents in native thornscrub woodland (88 percent) and replanted habitats (90 percent). *Oryzomys couesi* (Coues' rice rat) is a Mexican form reaching its northern distributional limits in the LRGV and distinguished as a unique species by Schmidt and Engstrom (1994). It is semi-aquatic, preferring marsh/grass zones near resacas, for example, and loss of such habitats and the general xerification of the riparian corridor in the LRGV have likely contributed to the Coues' rice rat being State listed as threatened in Texas (table 6).

Most recently, Dolman (2015) studied small mammals in 14 tracts of the mid-LRGV and found that species richness was positively correlated with tract size. Species composition was comparable to findings of Sternberg and Judd (2006), but in Dolman's study, capture rates of interior-adapted species were higher than edge-adapted species. This suggested that habitat restoration of natural woodland and thornscrub habitats in the areas studied likely had positive effects on some interior-adapted small mammals. Genetic assessments of white-footed mice in the 14 tracts studied by Dolman (2015) suggested a lengthy period of low population size during fragmentation and conversion of natural habitats to agricultural and urban areas beginning in the early 1900s. This was eventually followed by population expansion likely associated with restoration activities of the USFWS beginning in the late 1970s (Dolman, 2015).

Northern Ocelot in the LRGV

The ocelot was first listed as endangered by the USFWS throughout its foreign distribution in 1972, and the United States population of the northern ocelot was listed as federally endangered in 1982 (U.S. Department of Interior, Fish and Wildlife Service, 1982). The ocelot is a small, mainly nocturnal felid (fig. 14), native to subtropical and tropical regions in North, Central, and South America, currently ranging from the LRGV and southeastern Arizona (E. Fernandez, pers. commun.) south through Mexico to Peru and northern Argentina (Tewes and Schmidly, 1987; Murray and Gardner, 1997; USFWS, 2010a). In the United States, the ocelot once occurred in other parts of Arizona (López González and others, 2003; Holbrook and others, 2011) and much of Texas (Brown, 1990; Stangl and Young, 2011) into Arkansas and Louisiana, and fossil records exist from Florida (Navarro-Lopez and others, 1993; Murray and Gardner, 1997). Today, northern ocelots (subspecies *albescens*) in the United States occur in two populations in the LRGV, numbering about 50 individuals (Chappell, 2010; USFWS, 2010a; H. Swart, pers. commun.), and since 2009, a total of five Sonoran ocelots (subspecies *sonoriensis*) have been detected in Arizona (E. Fernandez, pers. comm.).

Ocelots use a wide variety of habitats in Mexico, Central America, and South America, including tropical dry forests, tropical humid forests, marshy areas, mangroves, riparian forests, and dry scrublands (Tewes and Schmidly, 1987; Murray and Gardner, 1997). Northern ocelots have been well studied in the LRGV (appendix *C*) and are now restricted to the densest remnants of thornscrub in Cameron and Willacy Counties, mainly Laguna Atascosa NWR and private ranches (Tewes and Everett, 1986; Harwell, 1990; Shindle, 1995; Shindle and Tewes, 1998; Haines, Tewes, Laack, and others, 2005; Haines, Janečka, and others, 2006; USFWS, 2010a). A population occurs in and around private ranches such as the Yturria Ranch, in which 3,201 ha (7,910 acres) are in conservation easements for northern ocelots (Chappell, 2010; B.R. Winton, 2015, pers. commun.), and the San Perlita and El Jardin tracts of the Lower Rio Grande Valley NWR in north-central Willacy County (Sternberg and Chapa, 2004; Haines, Grassman, and others, 2006). Presence of northern ocelots is an indicator of relative quality and connectivity of dense, remnant thornscrub habitat, making its preservation and restoration a critical conservation goal in the LRGV. Nevertheless, no Federal critical habitat has been designated for the northern ocelot in the United States (USFWS, 2010a).

Research since the 1980s, mainly under the direction of M.E. Tewes and through the Endangered Cat Research and Monitoring Program at Laguna Atascosa NWR, has uncovered many aspects of the biology and ecology of the northern ocelot to aid conservation and recovery (appendix *C*). Although data are still limited for some reproductive characteristics, parturition of northern ocelots around Laguna Atascosa NWR occurs from mid-April to late December, with typical litters of 1–2 kittens, each with a survival rate of 68 percent from birth to 1 year of age. Females select den sites generally within 10 m from or right amongst dense thornscrub; use 2–4 dens, 110–280 m apart, for each litter; and occupy dens for 3–64 days (Laack, 1991; Laack and others, 2005). Annual survival of northern ocelots from 1983 to 2002 differed significantly for resident (87 percent) and transient individuals (57 percent) but not by sex; transient northern ocelots were more likely to die from natural causes such as disease (e.g., Mercer and others, 1988; Pence and others, 1995, 2003) than residents, but both were equally affected by human impacts, mainly being hit by vehicles (Haines, Tewes, and Laack, 2005). Echoing early comments by Tewes and Miller (1987), more recent population viability analyses identified northern ocelot vehicle mortality as the single most important variable in long-term survival of northern ocelots in southern Texas, and without implementation of other recovery objectives (USFWS, 2010a), there was a 33 percent chance the population would be lost in 50 years; supplementation of the Texas population by translocation of northern ocelots from elsewhere also improved theoretical models of long-term viability (Haines, Tewes, Laack, and others, 2005; Haines, 2006; Haines, Tewes, and others, 2006; Haines and others, 2007). To enact the much-needed translocation, the Ocelot Recovery Team developed an Ocelot Translocation Plan (Translocation Working Group, 2009), and considerable research has been conducted in Mexico to support this effort (Stasey, 2012; Conservación y Desarrollo de Espacios Naturales, 2014).

Conservation of northern ocelots in the LRGV has benefited substantially from research on techniques to restore essential habitats, such as the correlations among preferred habitats with >95 percent canopy cover and particular soil series (Young and Tewes, 1994; Harveson, 1996; Harveson and others, 2004; Alexander and others, 2016); chemical immobilization protocols, applicable to similar felids around the world (Beltrán and Tewes, 1995; Shindle and Tewes, 2000); multiple approaches to remote sensing, video imaging, GIS, and landscape metrics to identify and assess essential habitats (Anderson and others, 1997; Tewes and others, 1999; Jackson, 2002; Harveson and others, 2004; Haines, Caso, and others, 2005; Jackson and others, 2005); scented hair snares to entice facial rubbing for collection of DNA in hair follicles (Weaver and others, 2005); first application of satellite-based telemetry on northern ocelots (Haines, Grassman, and others, 2006); and rapid whole genome amplification of DNA for conservation genetics work (Janečka, Grassman, and others, 2007; Janečka and others, 2008).

Figure 14. The endangered *Leopardus pardalis albescens* (northern ocelot). Perhaps more than any other species, the northern ocelot is emblematic of the substantial conservation challenges facing the biota of the Lower Rio Grande Valley (LRGV). About 50 northern ocelots likely remain in the LRGV. Left and bottom right ©Larry Ditto Nature Photography, used with permission; top-right photograph courtesy of D. Martinez, U.S. Fish and Wildlife Service.

Northern ocelots prefer the densest thornscrub habitats in the LRGV (Shindle and Tewes, 1998; Harveson and others, 2004; Jackson and others, 2005; Horne and others, 2009). These habitats are associated with certain soil types (Harveson and others, 2004) and have been severely depleted and fragmented, now making up <1 percent of the LRGV (Tewes and Everett, 1986). Loss of habitat, particularly large contiguous patches (Jackson and others, 2005), is the principal cause of decline of the northern ocelot in the LRGV, and its effects are multifaceted (Harveson and others, 2004; Haines and others, 2005a; Jackson and others, 2005). Throughout most of southern Texas, dense thornscrub has been eliminated or degraded by agriculture and urban development. With the loss of habitat, northern ocelots have been forced into smaller and smaller fragments of available habitat (Harveson and others, 2004; Haines, Tewes, Laack, and others, 2005; Jackson and others, 2005). To move between these small patches of habitat, northern ocelots often have no choice but to cross the increasing number of roads that have resulted from the continued human development in the LRGV (Tewes and Hughes, 2001). Northern ocelots also are occasionally killed directly by poachers or domestic dogs and after eating illegal poisoned baits used for “predator control” (Haines, Tewes, and Laack, 2005, p. 258; Laack and others, 2005).

Loss of habitat probably results in more interactions between transient and resident northern ocelots defending territories, resulting in death or injury (Haines, Tewes, and Laack, 2005). Interactions with *Lynx canadensis* (bobcats) also might negatively affect northern ocelots. Northern ocelots prefer dense brush, and bobcats generally occur in more open areas; however, it is unclear if this partitioning is the result of habitat preferences or competitive exclusion between the species (Horne, 1998; Horne and others, 2009). Most recently, camera traps found northern ocelots, living sympatrically with bobcats in Cameron County, mostly associated with corridors of brush, resaca edge, and drainage ditches and not brushy patches, which are typically thought of as a preferred core habitat of northern ocelots (Nordlof, 2015). Large, exotic nilgai have created trails through dense brush in areas that could be occupied by northern ocelots, permitting intrusion by bobcats and other mesocarnivores (Leslie, 2008). Recent dietary comparisons between northern ocelots and bobcats in southern Texas suggest some differentiation of prey size, with bobcats eating larger rodents and more lagomorphs than northern ocelots, but there was no clear partitioning of habitats, with both carnivores selecting prey about equally from thornscrub and grassland habitat (Booth-Binczik and others, 2013). Environmental contaminants have been found in northern ocelot tissue from the LRGV, but levels did not appear to affect their health (Mora and others, 2000)—a situation that could change with the expanding human population and warrants future monitoring.

Numbers of northern ocelots in the LRGV are very small and basically isolated in two locations about 30 km apart, and there is evidence of overall low nucleotide diversity (Janečka, 2006; Janečka, Walker, and others, 2007) and genetic differentiation between them (Janečka and others, 2011). Based on microsatellite analyses, effective population sizes of these remnant breeding populations (2.9 and 8.0 individuals) are well below the minimum level of about 50 individuals needed to maintain genetic health, suggesting that both populations will suffer (or have already suffered) from inbreeding depression and loss of adaptive variation, making them much more likely to be extirpated (Janečka and others, 2008). Prospects for colonization of additional habitat by transient northern ocelots are limited unless more thornscrub habitat associated with existing populations can be connected and protected from agricultural uses and urbanization (Janečka and others, 2011). As with population viability models, genetic deficiencies in the two populations suggest that translocation of taxonomically similar, but more genetically diverse, northern ocelots from Tamaulipas, Mexico, could improve recovery outlook (Translocation Working Group, 2009; Janečka and others, 2011).

Conservation strategies for the northern ocelot in the LRGV include habitat protection and restoration, land acquisition, creation of corridors linking populations and disjunct habitat that will encourage establishment of new populations, reducing automobile collisions, and introducing wild-caught northern ocelots from Mexico into the LRGV to bolster genetic diversity (e.g., Tewes and others, 1995; Harveson and others, 2004; Haines, Tewes, and others, 2005; Jackson and others, 2005; Haines, Tewes, and others, 2006; Janečka and others, 2011; Alexander and others, 2016). The urgent nature of reducing mortality from vehicle collisions was exemplified by the loss of five adult northern ocelots (about 10 percent of the known population) in an 8-month period in 2015 and early 2016 (H. Swarts, written commun.). An important means of minimizing vehicle collisions could be culverts under roads in areas near known territories, corridors, or other areas frequented by northern ocelots (Hewitt and others, 1998; Tewes and Hughes, 2001; Haines, Tewes, and Laack, 2005). Another strategy to minimize collisions is to use wildlife-crossing signs along roads where northern ocelots are known to occur, encouraging drivers to be cautious and slow down; northern-ocelot-crossing signs are not suggested because they could draw unwanted activities such as inadvertent harassment by nature enthusiasts and even poaching (Tewes and Hughes, 1991). Because almost 96 percent of Texas is privately owned, it will be essential that private landowners participate in habitat restoration and recovery efforts. Conservation easements and other incentives could engage private landowners to assist with habitat restoration efforts to benefit northern ocelots and other wildlife (Haines, Janečka, and others, 2006; Leggett, 2009).

Construction of the border fence by the U.S. Department of Homeland Security on the United States side of the Rio Grande has compromised recovery efforts for northern ocelots and other wildlife in the LRGV (see “Border Issues and Homeland Security” section). The fence could impede north-south movements of transient northern ocelots and other wildlife from Mexico and the United States along the lower Rio Grande and thereby restrict dispersal from extant populations and the possibility of establishment of a new resident population (e.g., Grigione and others, 2009; Abhat, 2011). Even artificial lighting along the United States-Mexico border associated with the wall could affect activity patterns and behavior of northern ocelots' prey (Grigione and Mrykalo, 2004). The last northern ocelot at Santa Ana NWR in the early 1990s reared two kittens there, and genetic analyses suggested that she originated from Mexico (Walker, 1997). How the border fence will affect such future movements is uncertain. Success in conserving northern ocelots in the LRGV will require integration of cross-border strategies (Grigione and others, 2009).

Ongoing Challenges Facing the LRGV

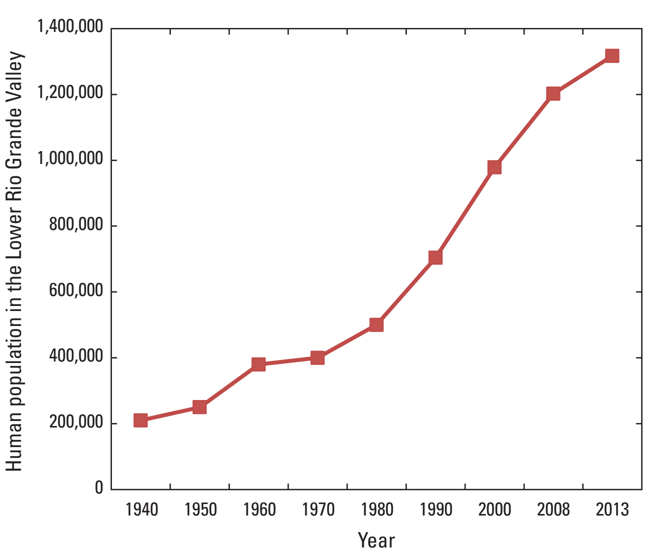
Since the arrival of Europeans in the 17th century, landscapes of the LRGV have been intensively modified, initially from overgrazing by livestock (Thompson, 1997; Tiefenbacher, 2001; Brush, 2005), which promoted growth of woody, thorny, and unpalatable plants and resulted in the gradual conversion of grasslands along the Gulf Coast and the northern part of the LRGV into areas dominated by mesquite and other woody species (Crosswhite, 1980). After the American Civil War, water manipulation (e.g., irrigation and flood control) and agriculture were initiated in the LRGV (Thompson, 1997; Tiefenbacher, 2001; Stubbs and others, 2003; Brush, 2005). Irrigation allowed settlers to grow crops that would have been impossible given the often dry conditions in the LRGV. Settlers cleared thornscrub, forests, and riparian woodlands to make room for cotton and citrus crops.

Tremblay and others (2005) calculated that native woodland loss in Cameron County from the 1930s to 1983 was 91 percent, as a result of agricultural expansion. This expansion greatly accelerated throughout the 20th century, and farm subsidies in the 1960s and 1970s encouraged clearing of more brush, even in Starr County which was generally thought to be too dry for farming. Human population growth in the LRGV also accelerated during the latter part of the 20th century, expanding housing developments, shopping centers, roads, and other aspects of human settlement and further impacting remnant native habitats (table 10.1 in Tiefenbacher, 2001).

Construction of dams, levees, and channels in the mid-20th century changed the flow and character of the Rio Grande and surrounding landscapes (Thompson, 1997; Stubbs and others, 2003). In particular, construction of Falcon Dam in 1953–54 reduced natural flooding that had regularly occurred in the river, causing changes in riparian forests, wetlands, and other areas that were dependent on freshwater and nutrient input from frequent floods; normal successional changes after such flooding disturbance were altered or ceased, resulting in loss of unique plant communities (e.g., Small and others, 2009). Reductions in flooding greatly affected permanence of an expanding human population in early decades of the 20th century (Thompson, 1997).

Human Population Growth and Associated Challenges

Since 1940, the population in the four-county area of the LRGV has increased by more than a million people, making it one of the fastest growing regions in the United States. In the 1960s through the 1980s, the population in the LRGV grew from about 400,000 people to nearly 700,000 (table 10.1 in Tiefenbacher, 2001; fig. 15), and since then, it has nearly doubled to an estimated 1,317,156 people in 2013 (U.S. Census Bureau, 2013). The McAllen-Edinburg-Mission



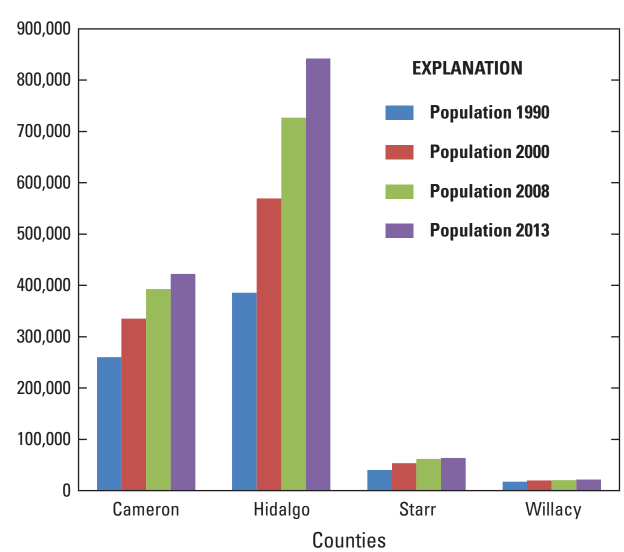


Figure 15. Nearly exponential growth of the human population in the Lower Rio Grande Valley from 1940 to 2013, projected to reach about 3 million people by 2050 (Stubbs and others, 2003; U.S. Census Bureau, 2013).

and Brownsville-Harlingen-San Benito areas have been, in recent years, among the fastest growing metropolitan areas in Texas and the United States (Chang and Davila, 2008). On the Mexican side of the Rio Grande, growth has been even greater; for example, Reynosa (633,730 people) and Matamoros (462,157 people) are considerably larger than their American counterparts, McAllen, Tex. (129,877 people), and Brownsville, Tex. (172,023 people), respectively (U.S. Census Bureau, 2010; Parcher and others, 2013).

From 2000 to 2010, human populations increased 36 percent in Hidalgo County, 21 percent in Cameron County, 14 percent in Starr County, and 10 percent in Willacy County, which experienced a slight decrease of about 1 percent from 2010 to 2013 (U.S. Census Bureau 2013). Growth trajectories are difficult to predict with certainty, but if growth from April 2010 to July 2013 in the two most populous counties is any indication, increases of 0.83 percent per year in Cameron County and 1.63 percent per year in Hidalgo County can be expected (U.S. Census Bureeau 2013). If this rate is realized in Hidalgo County, for example, the countywide population would rise from 815,996 people in 2013 to more than 1 million people in 2026. Stubbs and others (2003) predicted that populations in the LRGV will more than double by 2050 to as many as 3 million people.

Recent growth in the human population in the LRGV can be attributed to increased trade with Mexico and other parts of Central America. The North American Free Trade Agreement (NAFTA, U.S. Public Law 103–182), implemented in 1994, facilitated growth of trade throughout the Americas and Canada, and the LRGV "emerged as a [significant] warehouse and transportation center between Central America and the US [sic]" (Davila and others, 2005; Chang and Davila, 2008, p. 777). Rapid expansion of the human population and economy in the LRGV is related, in large part, to the strategic location next to a large manufacturing base in northern Mexico (Wynne, 1994; Chang and Davila, 2008). The LRGV in the United States has become a major shopping and vacation destination for Mexican citizens. Rapid development of the LRGV has not come without environmental consequences related to infrastructure to deal with air quality, water supply, wastewater treatment, solid waste disposal, and human health (e.g., Wynne, 1994; Ellenson and others, 1997; Mukerjee, 2001, 2002; Mukerjee and others, 2001; Davila and others, 2005; Chang and Davila, 2008).

As the human population continues to increase in the LRGV, urbanization will outpace agriculture as the principal cause of loss and fragmentation of native habitats (Marzluff and Ewing, 2001). Some estimates predict that 70 percent of humans—some 5 billion or more—will live in urban areas within the next 30 years (World Health Organization, 2013; Shanahan and others, 2015). The increase in the total amount of urban landscapes is problematic because it often has greater effects on wildlife than agricultural landscapes; urban areas persist longer and are more dissimilar to and disjunct from native habitats (Marzluff and Ewing, 2001). The almost certain increase in human numbers and associated urbanization in the LRGV will make it increasingly difficult for wildlife species to find enough habitat to maintain sustainable populations. Thus, maintaining and increasing protected areas in the LRGV—amidst an ever-increasing urban landscape—will become even more important in the years and decades to come. Importantly, wise planning of urban residential areas and parks can improve conditions for some plants, butterflies, birds, and other animals, providing more wildlife-friendly habitat than intensively cultivated areas.

Urbanization, Industrialization, and Economic Development

Urban landscapes now dominate many parts of the LRGV (fig. 16). From 1993 to 2003, total area of urbanized landscapes increased by 46 percent and total area of irrigated landscapes decreased by only 7.6 percent in Hidalgo (59.7 percent and 10.2 percent, respectively), Cameron (52.8 percent and 6.7 percent, respectively), and Willacy (25.7 percent and 5.9 percent, respectively) Counties (Huang and Fipps, 2006). This change clearly demonstrates that the landscape cost of urbanization in the LRGV has been at the expense of remaining natural habitats, not irrigated agricultural areas, which is also reflected in population densities: 1,277 people per square kilometer (493 people per square mile) in Hidalgo County, 1,181 people per square kilometer (456 people per square mile) in Cameron County, 129 people per square kilometer (49.8 people per square mile) in Starr County, and 97.1 people per square kilometer (37.5 people per square mile) in Willacy County (U.S. Census Bureau 2013).

The economy of the LRGV during early European settlement was based on cattle, sheep, and goat ranching, with other types of agriculture considered less important (Thompson, 1997). With enhanced irrigation and increased transportation capabilities such as railroads and major highways, cash crops like citrus fruits and sugarcane gradually replaced ranching as the most important component of the LRGV economy (Thompson, 1997; Mier and others, 2004). In recent years, however, there has been a shift from an agrarian economy to one based on services and trade with Mexico. In the early 2000s, 30 percent of jobs were in the service sector, 25 percent were in government, and 25 percent were in manufacturing, construction, and transportation (Mier and others, 2004).

A principal reason for the rise in trade with Mexico and subsequent boom in the human population and economic growth in the LRGV area was the establishment of maquiladoras—"twin plants," as they are known—beginning in the mid-1960s and greatly expanding after NAFTA was implemented in 1994 (Wynne, 1994; Gruben, 2001). Maquiladoras are manufacturing plants located on the Mexican side of the border. The Mexican government created a 20-km-wide strip of land along the border where duty-free foreign parts and goods could be imported; the intent was to increase employment, wages, and industrialization

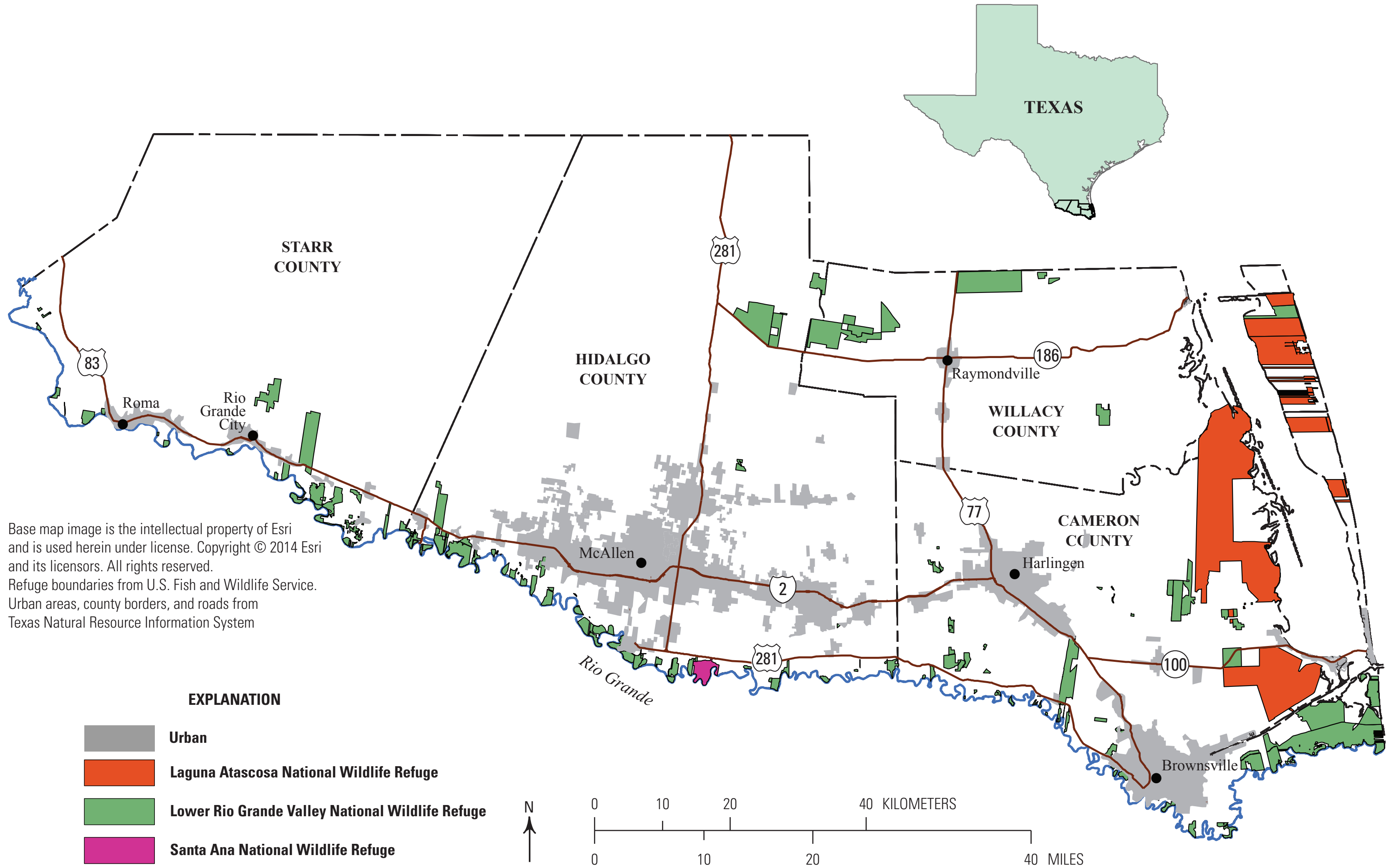


Figure 16. Urbanized areas in the Lower Rio Grande Valley, which form an almost continuous band from Roma, Texas, to beyond Brownsville, Tex. (Texas Natural Resources Information System, 2016).

in northern Mexico and decrease illegal immigration into the United States (Douglas, 2009). Maquiladoras typically import goods, mostly from the United States, which are then processed quickly and brought back to the United States for more processing or sale (Gruben, 2001; Douglas, 2009). The number of maquiladoras has risen significantly since NAFTA, and there has been corresponding growth in communities of northern Mexico and particularly in the LRGV (Chang and Davila, 2007; Douglas, 2009).

With increases in population and urbanized landscapes, the demand for new and larger roads has increased (McCray, 1998). Commerce with Mexico has also increased the need for more international bridges in the LRGV. The number of bridges has doubled from 5 international bridges in 1980 to 10 international point-of entry bridges by 2015; the Pharr-Reynosa International Bridge, south of McAllen, Tex., carried 93 percent of the 452,821 commercial trucks entering the United States in 2011, followed distantly by the Veterans International Bridge near Brownsville, Tex., at 5 percent (Rajbhandari and others, 2012). Collectively, this steadily increasing traffic puts added pressure on fragile riparian habitats and creates more barriers for wildlife and challenges to conservation activities (e.g., Dolman, 2015). Because the human population in the LRGV has increased, and will likely continue to do so, the numbers of roads and vehicles traveling on them will also increase, bringing more pressure on LRGV wildlife from collision-related injuries and mortalities (Loss and others, 2014b).

Energy Development

Oil and Gas

Energy demands in the LRGV will continue to increase with growing populations (e.g., Gray and others, 2013). Although the U.S. Government owns surface lands in the Lower Rio Grande Valley NWR, in many cases private parties own subsurface mineral rights and have the legal right to reasonable access to explore for and extract oil and gas. Ramirez and Baker Mosley (2015, p. 1) recently summarized increases in oil and gas development on USFWS properties, noting that they increase the “burden on lands set aside for natural resource conservation” and the likelihood of “impacts from brine, oil, and other hydrocarbon spills … [and] habitat alteration associated” with exploration and development of wells and pipelines. Across the entire NWR system of fewer than 560 properties and facilities in 2003, the Lower Rio Grande Valley NWR had the fifth highest number of oil and gas wells: oil, 4 active and 19 inactive; gas, 60 active and 79 inactive; oil and gas combined, 2 active and 8 inactive; and 172 in total. It ranked third in the number of injection wells with 5 active, 4 inactive, and 1 plugged.

Inactive, plugged, and improperly plugged wells can be overlooked relative to their potential ongoing environmental impact. In 2011, three wells posing potential hazards to East Lake in the Lower Rio Grande Valley NWR had to be plugged at a cost of $1.2 million to taxpayers because the owner/operator of the site could not be located (Covington, 2014). In March 2013, 25 barrels (1,050 gallons) of drilling mud were spilled at a drilling operation in the Lower Rio Grande Valley NWR (Ramirez and Mosley, 2015). Drilling and processing sites for oil and gas on Padre Island negatively impacted vegetative recovery by creating hard surfaces with oyster shells and caliche for the oil wells and roadways to them and alteration of site elevation, locally modifying the typically low relief of barrier islands (Carls and others, 1990).

Because of the high level of oil and gas development, personnel from the Lower Rio Grande Valley NWR have had substantial and ongoing roles in developing oil and gas management protocols and national policies that have refined techniques to reduce impacts to Federal resources and the general public and still afforded access to refuge properties. The need for protocols—consistent with current laws, policies, and industry practices—to assess impacts of oil and gas operations and follow-up inventory and monitoring on USFWS properties nationally (Ramirez and Mosley, 2015) has led to proposed changes to the 50-year-old regulations governing such activities. These changes are currently under public review before implementation (U.S. Department of Interior, Fish and Wildlife Service, 2015).

Wind Power

In the late 1980s, wind-power facilities did not exist in the LRGV. Since then, and particularly in the past 10 years, development of alternative energies to oil and gas has increased substantially in the United States. As of May 2015, wind-power facilities in the LRGV had 1,373 wind turbines of various heights and dimensions, with 132 proposed turbines (table 8). As maintained by the USFWS (2016a), the Federal Aviation Administration data in proximity to various cities in the LRGV show that most wind turbines occur near Harlingen, Raymondville, Rio Grande City, and Brownsville, Tex., with new developments proposed near Raymondville, Brownsville,

Table 8. Total number of wind turbines in proximity to various cities in the four-county area of the Lower Rio Grande Valley through May 2015 (U.S. Fish and Wildlife Service, 2016a).

City	Existing	Proposed/New location
Brownsville	108	58
Harlingen	512	0
Los Fresnos	120	0
Raymondville	345	74
Rio Grande City	228	0
South Padre Island	3	0
Sullivan City	57	0
Total	**1,373**	**132**

and Los Fresnos (fig. 17). Fifteen companies were actively developing wind-power facilities in the LRGV in mid-2015, but three companies owned and operated 90 percent of the wind turbines: FPL Energy, Inc., alone or partnered with Horse Hollow Wind Energy, 586 turbines; Renewable Energy Systems (Americas), Inc., 423 turbines; and Buffalo Gap Wind Farm, LLC, 345 turbines.

Mortalities of birds and bats occur from collisions with manmade structures, including wind turbines (National Research Council, 2007; Sovacool, 2009; Loss and others, 2012). Estimates of wind turbine losses for birds in the United States (140,000–368,000 birds per year—Loss and others, 2013a; Erickson and others, 2014) are far less than estimated mortalities from collisions with communication towers (4–5 million birds per year—Erickson and others, 2005), power lines (12–64 million birds per year—Loss and others, 2014a), vehicles (89–340 million birds per year—Loss and others, 2014b), buildings (365–988 million birds per year: 56 percent at low-rise buildings of 4–11 stories, 44 percent at residences of 1–3 stories—Loss, Will, Loss, and Marra, 2014), and feral/domestic cats (1.4–3.7 billion birds per year and 6.9– 20.7 billion mammals per year—Loss and others, 2013b). Unfortunately, no research on effects of wind turbines in the LRGV (or other like hazards) has been published and presumably collected, but the fact that two major migratory flyways (Mississippi and Central) converge in the LRGV is of concern.

Graham and Hudak (2011) calculated a potential hazard index (PHI) from wind-power facilities for 31 rare, threatened, or endangered bird species and 10 bat species in Texas; PHI was a weighted average of a species' percentage of known distributional area in each of six wind-speed classifications at a height of 50 m in Texas. Mean PHI for birds was 2.1 (range = 1–3.5), and species of conservation interest in the LRGV had relatively high PHIs: tropical parula (2.29), rose-throated becard (2.29), northern beardless-tyrannulet (2.24), *Peucaea botterii texana* (Texas Botteri's sparrow—2.23), and northern aplomado falcon (2.23). Mean PHI for bats was 2.29 (range = 1–2.74), and species of conservation interest in the LRGV had relatively high PHIs: southern yellow bat (2.36) and Mexican long-tongued bat (2.15). This index could not incorporate actual mortalities of birds and bats because such data are not widely available (Graham and Hudak, 2011), but it did provide a generalized indication of potential hazards to species of concern in the LRGV and elsewhere in Texas.

Recently, the USGS proposed a standardized methodology to assess regional and national impacts of wind-power development on birds and bats; it relies on often-limited, species-specific data to assess probability of risk to overall populations of birds and bats before developing wind power in a specific area (Diffendorfer and others, 2015). Future applications of this methodology could benefit conservation relative to wind-power development near the STRC and elsewhere in the LRGV.

Figure 17. Wind-power development in the Lower Rio Grande Valley, which has grown from zero in the late 1980s to about 1,400 wind turbine towers operated by 15 companies and often juxtaposed near or in important brushlands and coastal habitats; photos show wind turbine towers north of Los Fresnos, Cameron County, Texas. Photographs courtesy of Chris Perez, U.S. Fish and Wildlife Service.

Pollution and Waste Management

Significant effects of border growth and manufacturing activities are associated with water and air pollution, waste management, sanitation, and human health problems (e.g., Warner, 1991; Akland and others, 1997; Garcia and others, 2001; Peterson and others, 2001; Callegary and others, 2013). Air pollution in the Matamoros-Reynosa region of Mexico in the LRGV came mainly from vehicular sources (80.8 percent) and secondarily from a power plant in Rio Bravo (17.7 percent) and industry (1.5 percent—Mejia-Velazquez and Rodriguez-Gallegos, 1997). Various agricultural practices can be significant sources of water pollution. Recent monitoring of the Arroyo Colorado in the LRGV suggested that, despite a 30-percent loss of irrigated water from runoff, pollutants reaching the Arroyo Colorado, particularly soluble nitrogen compounds, were reduced by the combination of residue management, subsurface tile drainage, and education of farmers to closely monitor irrigation applications relative to real-time runoff (Enciso and others, 2014). Agricultural burning is another factor affecting air quality and is routinely done on sugarcane fields from November through March in the LRGV (Dennis and others, 2002).

Solid waste management is an ever-increasing challenge in the LRGV as urbanization expands on either side of the United States-Mexico border (Davila and others, 2005; Chang and Davila, 2008; Chang and others, 2008). Due to rapid population growth and increasingly limited landfill space, the LRGV region, particularly the highly urbanized areas in Hidalgo and Cameron Counties, will face increasing pressure to successfully manage human waste while maintaining environmental standards in the coming decades. Annual waste production in Hidalgo, Cameron, and Willacy Counties in the early 2000s amounted to 410,000 tons per year, handled by six landfills with “only 12 more years of landfill life” (Chang and Davila, 2008, p. 778). Substantial energy recovery could be possible from recycling of plastic and paper in the waste stream of the LRGV (Chang and Davila, 2008). Somewhat paradoxically, authorized tire disposal costs $5 per tire. Some residents in the LRGV would rather keep the $20 disposal fee for a new set of tires than pay it, so they stockpile or dump old tires, often on remote tracts of the Lower Rio Grande Valley NWR. Dumped tires create sanctuaries for exotic Africanized honey bees and nesting sites for mosquitoes—both of which are a nuisance to humans (see “Exotic and Invasive Species” section).

Human Health and Associated Benefits of Land Conservation

Communities in the LRGV have long been considered among the poorest in the United States, with weak healthcare opportunities and delivery (Maril, 1989) and poor living conditions for some in unregulated settlements, or “colonias” (Rivera, 2014). As of 2012, 34.9–39.9 percent of people in the LRGV live under the poverty level, in contrast to an average of 17.4 percent throughout Texas (U.S. Census Bureau, 2013). A dual system of human healthcare exists in the LRGV, with contemporary medical services mixed with traditional remedies from folk healers, or “curanderos,” and midwives, or “parteras” (Maril, 1989; Thompson, 1993; Burk and others, 1995; Keegan, 1996; Richardson and others, 2012). Workers in the LRGV are often dependent on jobs that can be injurious to their health, pay low wages, and do not provide adequate health insurance. Healthcare literacy (Olney and others, 2007) and language barriers to understanding healthcare options and procedures (Martinez, 2008) have also been challenging for some residents of the LRGV.

As a result of healthcare limitations in the LRGV (e.g., Mier and others, 2008), a significant increase in Federal and State healthcare dollars and programs were provided in the 1970s and 1980s (Maril, 1989), yet healthcare costs and opportunities are still out of reach of many of residents of the LRGV, unless they are covered under assistance programs like Medicare. In 2009, McAllen, Tex., in Hidalgo County had one of the most expensive healthcare markets in the United States, with Medicare costs of $15,000 per enrollee in 2006—twice the national average and $3,000 above the average per capita income of only $12,000 (Gawande, 2009). Although medical facilities in the area of McAllen, Tex., were of equal quality, if not better than, those in comparable cities, excessive testing, surgery, hospital stays, and homecare, perhaps coupled with fear of lawsuits, seemed to cause overuse of medical care in McAllen, Tex. (Gawande, 2009).

The growing population in the LRGV has resulted in associated medical issues, particularly among Mexican-Americans who composed 87.2–95.7 percent of the populations in Cameron, Hidalgo, Starr, and Willacy Counties in 2010 (U.S. Census Bureau, 2013). Mexican-American residents of the LRGV have experienced high rates of clinical anxiety (Glover and others, 1999); the highest rates of and deaths from diabetes in Texas (Larme and Pugh, 2001; Brown and others, 2002; Mier and others, 2007); low rates of mammography in farmworker communities (Palmer and others, 2005); low frequencies of prenatal diagnoses of birth defects (Waller and others, 2000); higher than average rates of adolescent obesity (Lacar and others, 2000); barriers to adolescent mental healthcare services (Pumariega and others, 1998); and correlation of poverty and country of origin with adolescent depression, drug use, suicide (Swanson and others, 1992), and insomnia (Roberts and others, 2004). Among adults, the obesity rate is 38 percent, and heavy drinking is 60 percent higher than the national average (Gawande, 2009).

Open spaces such as city parks, outdoor classrooms, nature centers featuring birds and butterflies, and closely associated wildlife refuges and State and national parks enhance human health by encouraging physical activity and providing psychological well-being and community engagement (Maller and others, 2008, 2009; Shanahan and others, 2015; fig. 18). These areas also serve to fundamentally connect people with biota and ecological processes that they

Figure 18. Some of the many outdoor open-space recreational and educational opportunities available in the Lower Rio Grande Valley. ©Larry Ditto Nature Photography, used with permission.

depend on, serving as educational platforms to reconnect people with their evolutionary past and ecological future (Maller and others, 2009). Community-based multidisciplinary models exist that attempt to enhance physical activity, and therefore overall health, by addressing social and physical environments relative to community layout, opportunity, and policy (Sallis and others, 2006). The various cities in the LRGV are rapidly becoming a unified metropolis, stretching nearly the entire length of the LRGV. Fortunately, many open spaces still remain in the LRGV, and their enhanced use by local people could improve physical and mental health (e.g., Bratman and others, 2015) and foster an appreciation of conservation goals of the various city, county, State, and Federal agencies (U.S. Fish and Wildlife Service, 2016c). The challenge will be to vigorously engage citizens of the LRGV when many people are detached from the natural world and more inclined to focus on sedentary activities that do not foster good health (Shanahan and others, 2015).

Agriculture

Changes in Crop Production

Crop production is still very important to the economy of the LRGV, enhanced by the long growing season of more than 300 frost-free days and still relatively rich deltaic soils (Stubbs and others, 2003). As it was in the late 1980s (Jahrsdoerfer and Leslie, 1988), Hidalgo County ranks first among Texas counties for 90 percent of its cash receipts, totaling $314.3 million per year, coming from crops, primarily sugarcane, grain, produce (e.g., cantaloupes, onions, broccoli, and tomatoes), and citrus; Cameron County ranks second in sugarcane production and generates about $112 million per year; and Starr and Willacy Counties generate considerably less agricultural revenue at $64.4 million per year and $51.2 million per year, respectively

(Cruce Alvarez and Plocheck, 2012). Most of these crops require irrigation to be profitable in the seasonally dry climate of the LRGV, although some dryland crops such as grain sorghum are also produced.

Since the late 1980s, the total area of the LRGV in crop production decreased as urbanization increased, and the importance of various crops has changed (Ellard and Patrick, 1988; Cruce Alvarez and Plocheck, 2012). Severe freezes in 1983 and 1989 destroyed thousands of hectares of citrus trees and started the trend of decreasing agriculture, associated with expanding urbanization (Stubbs and others, 2003). The recent arrival of "citrus greening" carried by the Asian citrus psyllid *Diaphorina citri*, capable of causing rapid die-off of trees (French and others, 2001), has resulted in quarantines in expanding areas of the LRGV, reduced production, and acreages removed from citrus production (www.texascitrusgreening.org/psyllid-control-treatments).

From 1993 to 2003, irrigated land generally decreased in Cameron, Willacy, and Hidalgo Counties (Huang and Fipps, 2006). In Cameron and Hidalgo Counties, there were more than 142,854 ha (353,000 acres) of irrigated cropland in 1997, which decreased 16 percent or 22,258 ha (55,000 acres) by 2007. Concomitantly, farms and ranches in Cameron and Hidalgo Counties decreased by 35,622 ha (88,025 acres), and only 2–3 percent of Willacy and Starr Counties were irrigated—both counties best known for livestock production (Wilkins and others, 2009). Along with losses of native habitats to agricultural activities, considerable escalation of the use of complex chemicals and biological agents to fight agricultural pests and diseases occurred from the 1940s onward, resulting in growing concern about and documentation of the toxicity of many of these chemicals to the biota, including humans, of the LRGV (Tiefenbacher, 2001).

Pesticides, Herbicides, and Associated Contamination

Research on effects of insecticides, herbicides, and fungicides to nontarget biota in the LRGV was just beginning in the 1980s. With the creation of the U.S. Environmental Protection Agency (EPA) in 1970, some of most harmful pesticides, particularly those that were organochlorine based, were banned early (e.g., dichlorodiphenyltrichloroethane [DDT], dieldrin, mirex, alrin, and endrin). Of the 98 "commonly used" pesticides in the LRGV up until the late 1980s (table 4 in Jahrsdoerfer and Leslie, 1988), many have been banned since or registered with restricted use by the EPA (e.g., application by certified/professional applicators, or designated use on only particular crops and areas). Six of the 35 organophosphate insecticides listed by Jahrsdoerfer and Leslie (1988) are now banned by the EPA, and 6 have restricted use permits; 2 of the 8 n-methyl carbonate insecticides are banned, and 4 are in restricted use; 14 of the 18 organochlorine insecticides—a particularly problematic class of chemicals relative to lethality and potential to bioaccumulate in nontarget organisms—are banned, and 2 have restricted use; 1 of 25 herbicides is banned, and 2 have restricted use; and none of the 12 fungicides are banned or have restricted use, but 2 are no longer marketed.

Impacts of many contaminants can be evident for decades (e.g., Mora and Wainwright, 1998), and despite improvement of regulations for pesticide use in the United States and banning those most harmful, deleterious effects of early use of some pesticides have been documented in the LRGV (Papoulias and Parcher, 2013; table 9). Origins of these contaminants were largely agricultural, and the highest levels were typically found in aquatic systems from agricultural runoff. Fish in the lower Rio Grande can still contain high levels of contaminants (e.g., DDT metabolites, chlordane-related compounds, dieldrin, and toxaphene); maximum concentrations were evident in *Ictalurus punctatus* (channel catfish) from near Mission and Brownsville, Tex. (Schmitt and others, 2005). *Micropterus salmoides* (largemouth bass) and common carp in the lower Rio Grande had burdens and reproductive impairments consistent with chronic exposure to contaminants (Schmitt and others, 2005).

Some research on avian species since the late 1980s suggests that effects of past pesticide contamination in the LRGV have abated. Levels of 57 contaminants, including trace elements, organochlorines, and hydrocarbons, were generally in background levels in redheads from the Upper and Lower Laguna Madre (Michot and others, 1994); dichlorodiphenyldichloroethylene (DDE) declined in eggs of *Rynchops niger* (black skimmers) from 1979 to 1984 near Laguna Vista in south Lower Laguna Madre (Custer and Mitchell, 1987); and significant declines from the 1970s and 1980s were reported in levels of organochlorines (e.g., DDE and polychlorinated biphenyls [PCBs]) and trace elements in nesting colonial waterbirds (*Hydroprogne caspia* [Caspian terns], *Ardea herodias* [great blue herons], *Egretta thula* [snowy egrets], and *Egretta tricolor* [tricolored herons]) in the Lower Laguna Madre (Mora, 1996a, 1996b). Similar results of low to background levels of contaminants have been noted for *Plegadis chihi* (white-faced ibis—Custer and Mitchell, 1989), and white-winged doves collected at eight sites in the LRGV during summer 2003 had only background levels of potentially harmful elements (e.g., arsenic, chromium, and lead) and organochlorines (e.g., DDE, dieldrin, and chlordane) known to impair survival and reproduction in birds (Fredricks and others, 2009).

DDE decreased about 66 percent in adult and subadult peregrine falcons migrating through the LRGV from 1978 (1.0 microgram per gram [µg/g] wet weight) to 1994 (0.34 µg/g); no other organochlorine pesticides were detected in 1994 but were routinely detected prior to that (Henny and others, 1996). Addled eggs of northern aplomado falcons in the LRGV have been assessed for contaminants for many years. Although organochlorine byproducts such as DDE have been variously reported in addled eggs of northern aplomado falcons, they generally have been detected in low background

Table 9. Research in the Lower Rio Grande Valley and nearby Mexico since the late 1980s indicating elevated and (or) higher-than-threshold levels of contaminants known to cause deleterious effects to organisms.

[DDE, dichlorodiphenyldichloroethylene; PCB, polychlorinated biphenyl]

Location or organism studied	Contaminant	References
Abiotic		
Sediments in Laguna Madre	Heavy metals: cadmium and lead	Sharma and others (1999)
	Petroleum hydrocarbons (benzene, methyl and dimethyl naphthalene)	Sharma and others (1997)
Soil contamination from oil and gas on Padre Island	Heavy metals: barium, chromium, lead, and zinc	Carls and others (1995)
	Petroleum hydrocarbons	Carls and others (1995)
Biotic–avian		
Butorides virescens (green heron) eggs	Organochlorine: DDE and Toxaphene[a]	Wainwright and others (2001)
Falco femoralis septentrionalis (northern aplomado falcon) eggs (United States and Mexico)	Organochlorine: DDE and PCB	Mora and others (1997, 2008)
	Heavy metals: mercury	Mora and others (1997, 2008)
Northern aplomado falcon prey	Organochlorine: DDE (*Quiscalus mexicanus* [great-tailed grackle])	Mora and others (1997)
	Heavy metals: mercury (*Sturnella magna* [eastern meadowlark])	Mora and others (1997)
Petrochelidon fulva (cave swallow) and *Petrochelidon pyrrhonota* (cliff swallow) liver and muscle	Organochlorine: Toxaphene[a]	Maruya and others (2005)
	Organochlorine: DDE and Toxaphene[a]	Mora and others (2005, 2006)
Tringa semipalmata (willet) liver	Arsenic	Custer and Mitchell (1991)
Overview/synthesis	Heavy metals: mercury	Mora and Wainwright (1998)
	Trace elements: selenium	Mora and Wainwright (1998)
Biotic–aquatic		
Carp in JAS Farm Lake (Cameron County)	Organochlorine: DDE	Wainwright and others (2001)
Fish in lower Rio Grande Basin, particularly *Micropterus salmoides* (largemouth bass) and *Cyprinus carpio* (common carp)	Chlordane related	Schmitt and others (2005)
	Organochlorine: DDE, Dieldrin,[b] and Toxaphene[a]	Schmitt and others (2005)
Fish in resacas (United States and Mexico)	Arsenic	Mora and others (2001)
	Organochlorine: DDE	Mora and others (2001)
Shrimp and *Lagodon rhomboids* (pinfish)	Heavy metals: nickel and chromium	Custer and Mitchell (1993)
Overview/synthesis	Heavy metals: mercury	Mora and Wainwright (1998)
	Trace elements: selenium	Mora and Wainwright (1998)

[a]Banned for most uses in the United States in 1982 and all uses in 1990 and globally by the Stockholm Convention on Persistent Organic Pollutants in 2001.

[b]Banned for all uses in the United States in 1987.

levels beginning in the early 1990s (Mora and others, 1997, 2008), and similar detections were found more recently in neighboring Chihuahua and Veracruz, Mexico (Mora and others, 2011). Troubling, however, is that these studies suggest that Hg is elevated in addled eggs (Mora and others, 2008), which may be traceable to the falcon's prey (Mora and others, 1997; table 9). It has been recommended that Hg levels be continually monitored in addled eggs of northern aplomado falcons in the LRGV (Mora and others, 2008).

Primary research on invertebrates in the LRGV has been largely focused on insect pests, many of them lepidopterans. Most research has been ecological rather than pesticide based and has focused on lepidopteran cabbage pests (Cartwright and others, 1987); citrus pests such as *Gonodonta nutrix* (citrus leafminer) (Legaspi, French, and others, 1999a); potato pests such as sharpshooters and leafhoppers (both family Cicadellidae) and jumping plant lice (family Psyllidae—Goolsby, Bextine, and others, 2007; Munyaneza and others, 2007); basic research and parasitoid control of *Bemisia* spp. (silverleaf whiteflies—Norman and Sparks, 1997; Riley and Ciomperlik, 1997; Liu, 2000; Goolsby and Ciomperlik, 2008); cotton pests such as *Anthonomus grandis* (boll weevils—Summy and others, 1992; Showler and Cantú, 2005; Greenberg and others, 2007), *Euschistus* spp. (stink bugs—Hopkins and others, 2009), and *Spodoptera exigua* (beet armyworms—Pair and others, 1991, 1995; Summy and others, 1996); corn pests such as *Helicoverpa zea* (corn earworms—Raulston and others, 1990, 1992; Lingren and others, 1994; Pair and others, 1995) and fall armyworms (Raulston and others, 1992; Wolf and others, 1995); sugarcane pests and their parasites such as invasive pyralid stem borers (Youm and others, 1990; Legaspi and others, 1997, 2000; Legaspi, Legaspi, and others, 1999; Meagher and others, 1998; Sétamou and others, 2002) and the sugarcane tingid *Leptodictya tabida* (Sétamou and others, 2005); and general control of pests such as aphids by treating cotton with kaolin (Showler and Sétamou, 2004). Some research has focused on biological control of pests with exotic and potentially invasive parasitic organisms (e.g., Cartwright and others, 1987; Summy and others, 1992; Legaspi and others, 1997; Meagher and others, 1998; Goolsby and Ciomperlik, 2008).

There has been limited research on effects of current pesticide use on the LRGV's biota. Some life stages of these insects might be important to birds, reptiles, and amphibians (e.g., Parker and Goldstein, 2004), and those that feed in agricultural areas may be harmed by chemical control of pests (e.g., Corson and others, 1998). Therefore, USFWS places significant importance on minimizing effects of pesticides on pollinators by avoiding microencapsulated pesticides similar in size to pollen, reducing drift from applications by encouraging ground versus aerial equipment, and minimizing the time pesticides remain on plant parts, which can reduce effects on nontarget insects (USFWS, 2016b). The USFWS also cooperates with 26 other agencies and organizations to improve conservation of *Danaus plexippus* (monarch butterflies), which involves reducing pesticide exposure (Monarch Joint Venture, 2015).

Under current Federal law, chemical companies that want to market a new pesticide for use in the United States must register it (and reregister it for any new use) with the EPA and provide assurances that it poses no risk to human health and no unreasonable risks to the environment (U.S. Environmental Protection Agency, 2016a). The EPA also encourages producers to develop Integrated Pest Management (IPM) plans to minimize damage to crops while reducing possible pesticide hazards to people, property, and the environment (U.S. Environmental Protection Agency, 2016b). Various IPMs dating back to the 1960s were implemented in the LRGV, now often resulting in reduced need for repeated pesticide applications on crops such as cotton (Castro and others, 2007; Greenberg and others, 2012), cabbage (Cartwright and others, 1987), and potatoes (Goolsby, Adamczyk, and others, 2007). The USFWS's Pesticide Use Proposal System requires regional or national oversight to approve use of various chemicals on its land, and the Lower Rio Grande Valley NWR authorizes and closely manages pesticide and herbicide use on its land to ensure minimal harm to desirable plants and animals.

Despite positive progress to minimize pernicious effects of pest management, continued vigilance is needed to conserve all aspects of the LRGV's biotic richness. Tacha and others (1994) found chronic and widespread exposure of white-winged doves to anticholinesterase compounds (many of them banned now) in the LRGV, but the effects of long-term, sublethal exposure to pesticides are still largely unknown. Relatively recent comprehensive profiles of 20 organochlorines, 21 polychlorinated biphenyl congeners, and toxaphene in tissue of white-winged doves showed that exposure in the LRGV does not impair reproduction or survival (Fredricks and others, 2009). In sharp contrast, neonicotinoid insecticides, registered and approved for use in more than 120 countries including the United States, have recently been implicated in colony collapse disorder of honey bees (Lu and others, 2014; Rundlöf and others, 2015); in 2014, the USFWS became the first Federal agency to announce plans to phase out the use of all neonicotinoids on its properties.

Continued Agricultural Pressure on Native Habitats and Water Resources

European explorers and settlers in the LRGV introduced domestic grazing animals as early as the 1700s. Organized ranches soon followed, and by the Mexican-American War in the mid-19th century, there was intense grazing pressure from free-ranging cattle across much of the LRGV (Thompson, 1997). After the American Civil War, thousands of veterans and others came to the LRGV, in part to round up free-ranging cattle and drive them north to waiting railroads where they were shipped to growing urban centers elsewhere in the United States or used to stock significant parts of the American West. This "cowboy model" remains one of the most enduring symbols of the American "Wild West" and owes much of its genesis and early history to what occurred in the LRGV (Thompson, 1997). The importance of livestock is not what it once was, perhaps related to quarantines imposed to control tick fever (see "Exotic Mammals" section). Nevertheless, between 1997 and 2007 in Cameron and Hidalgo Counties, the area of nonnative pasture for livestock—some of which represents plantings of exotic grass (K. Wahl, pers. commun.) at the expense of native grassland—increased 31.4 percent from 31,270 ha (77,270 acre) to 41,089 ha (101,534 acres) (Wilkins and others, 2009).

Most remnant patches of native habitat in the LRGV that existed in the late 1980s were protected by NWRs, State parks, and private conservation organizations (e.g., the Nature Conservancy), and they largely remain protected as of early 2016. Efforts to acquire more intact native habitats and restore former agricultural lands in the Lower Rio Grande Valley NWR have met with some success. Nevertheless, despite tax incentives for private landowners in Texas to manage their land to benefit wildlife, no land had been officially designated for tax appraisal purposes in the LRGV up until 2007, perhaps a reflection of greater value when land is in agricultural production or sold outright (Wilkins and others, 2009). Average value of “farms, ranches, and forestland” in Texas in 2007 ($1,196 per acre) was about 2.4 times lower than its average value in the LRGV ($2,900 per acre) (Wilkins and others, 2009, p. 2). Positive progress notwithstanding, native habitats in the LRGV, particularly in the riparian corridor, remain small and fragmented—even more so with construction and completion of the border fence (see “Border Issues and Homeland Security” section). Thus, continued pressure from agricultural use in the LRGV, along with expanding urban areas, makes it important to acquire, protect, and restore native habitat before it becomes increasingly unsuitable or, worse, unavailable.

Flood Control and Water Development

The Rio Grande is the fifth largest river in North America and the longest border river between two countries in the world (Stubbs and others, 2003; Mathis, 2005; Updike and others, 2013). The LRGV has the smallest major watershed (26,522 km^2) along the United States-Mexico border, with about 60 percent (15,942 km^2) of the watershed draining from Mexico and about 40 percent (10,580 km^2) from the United States (Parcher and others, 2013). Regular flood-pulse cycles of large river systems such as the Rio Grande are an essential form of natural disturbance, providing regular selection pressure on organisms living with them (e.g., Bayley, 1995; Molles and others, 1998; Small and others, 2009). When a flood-pulse cycle is disrupted, it can decrease plant and animal richness (Mathis and others, 2004; Small and others, 2009). Maintenance and restoration of the flood-pulse cycles in these waterways are critically important to conservation of ecological function, quality, and biodiversity (e.g., Richter and Richter, 2000; Small and others, 2009). Much of the flood-pulse cycling has been lost in the LRGV, rendering some habitat restoration projects difficult or impossible to accomplish without some type of prescribed flooding (Richter and Richter, 2000; Small and others, 2009).

Flood-control Activities

Prior to large-scale water-control efforts in the late 1930s, the Rio Grande overflowed its banks and flooded the LRGV on at least 23 separate occasions, often associated with hurricanes and significant loss of life and property (Thompson, 1997; Tiefenbacher, 2001; Stubbs and others, 2003). As a result, the International Boundary and Water Commission (IBWC), established in 1889 in cooperation with Mexico, initiated numerous flood control projects on the lower Rio Grande from Peñitas in Hidalgo County to the Gulf of Mexico; by 1950, the IBWC had completed 75 percent of planned projects that included 233 km (145 mi) of floodways (e.g., Main and North Floodways) and 459 km (285 mi) of levees along the river (Tiefenbacher, 2001; Stubbs and others, 2003).

Falcon Dam was constructed in 1953–54 and is the largest dam on the lower Rio Grande; however, it was not the last dam constructed to control the Rio Grande but did provide dependable water for irrigation (fig. 19). In 1960, the Anzalduas Dam was completed downriver from Falcon Dam; it was designed to divert floodwaters into floodways on the United States side of the river and into irrigation canals on the Mexican side. The third major dam, Retamal Dam, was constructed in the 1970s downriver from Anzalduas Dam; it further diverted floodwaters into floodways on the Mexican side of the river. Numerous pumping stations have been built along the river between Anzalduas Dam and Brownsville, Tex., to take water out of the Rio Grande for irrigation and municipal and (or) industrial uses. Numerous weirs have been constructed below Retamal Dam to raise water levels for pumping into canals for irrigation purposes along the lower reaches of the Rio Grande. Currently, the IBWC manages Anzalduas and Retamal Dams, 500 irrigation and drainage structures, and 435 km (270 mi) of levees, among other projects (International Boundary and Water Commission, 2016).

As immigrants continued to settle in the LRGV throughout the 1900s, new and varied forms of agriculture and crops were introduced (table 10.1 in Tiefenbacher, 2001). As agrotechnology advanced, waterways were manipulated more and more for flood control, agriculture, industry, and drinking water. Apart from IBWC, various irrigation districts were set up and managed separate irrigation systems consisting of massive pump stations along the Rio Grande itself and ditches, canals, and weirs to transport water to rapidly growing needs of farms and towns of the LRGV (Stubbs and others, 2003). The Arroyo Colorado, the primary distributary of the lower Rio Grande in the United States, was dredged and altered to satisfy demands of irrigation, navigation, and flood control (fig. 19); it no longer connects to the Rio Grande and is completely diverted into Laguna Madre (Small and others, 2009).

Irrigation and Water Rights

A landmark 1904 amendment to the Texas Constitution allowed public development of the State’s water resources. After that, farmers bought out private irrigation companies and established the first public irrigation districts (Tiefenbacher, 2001; Stubbs and others, 2003). The districts were organized to provide “irrigation, drainage, flood control, and wholesale water and untreated water supply” (Stubbs and others, 2003, p. 15). Initially, irrigation districts encompassed all or part of one county, including cities and towns, but eventually cities and towns were not included in the irrigation-district system unless requested. There are now 29 irrigation districts in Cameron and Hidalgo Counties that supply all irrigation and municipal water needs in the LRGV (Stubbs and others, 2003).

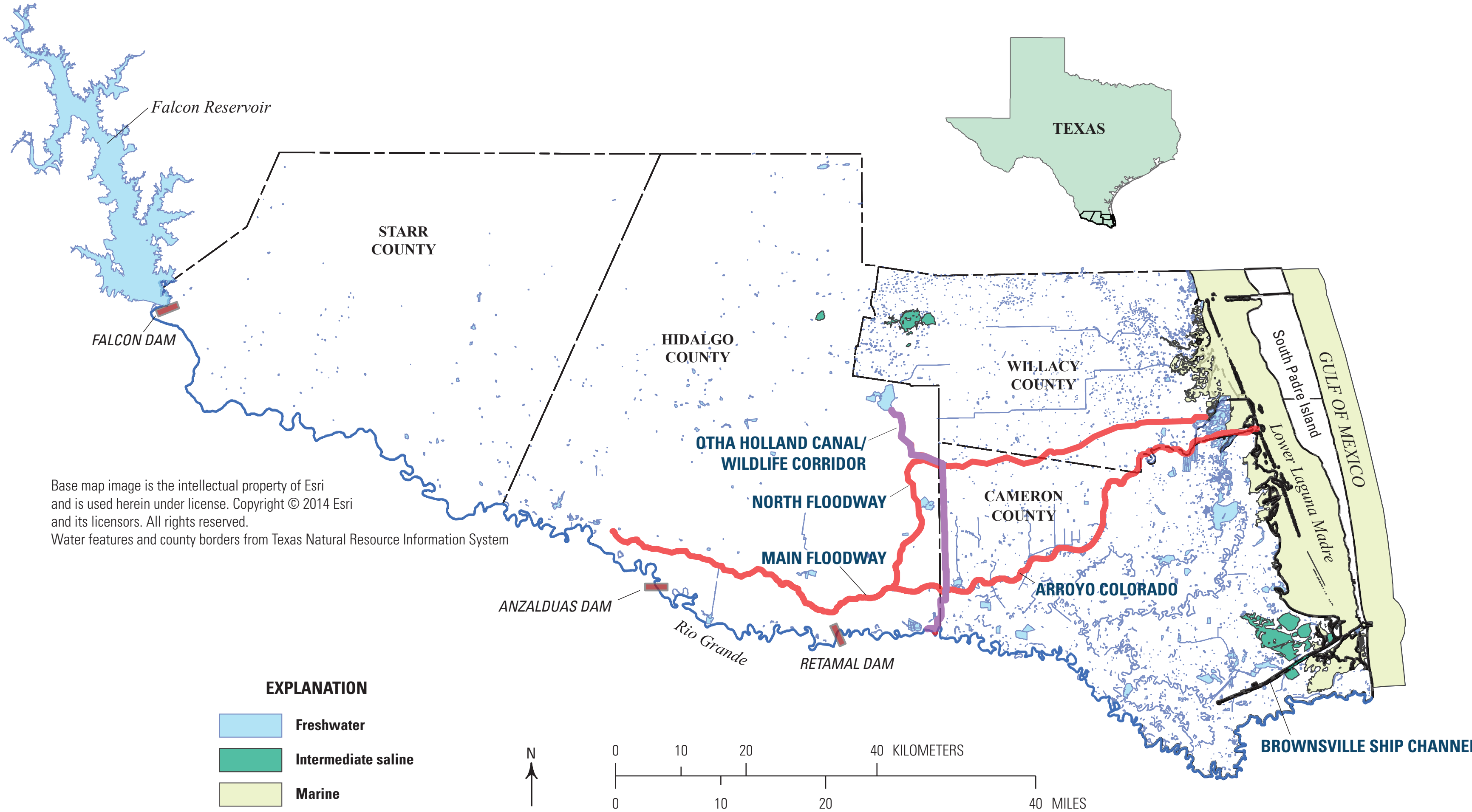


Figure 19. The three major dams, water-control canals, and the Arroyo Colorado in the Lower Rio Grande Valley (LRGV) that negatively affect remnant flood-plain forests and restoration efforts along the LRGV by altering, and even eliminating, natural flow and flooding regimes.

For much of the 19th century, Texas had a riparian water rights system that simply gave rights to those whose land abutted surface waters (Stubbs and others, 2003). After 1895, the State used a dual system by which owners of land purchased before 1895 maintained their riparian water rights. With the passage of 1895 Irrigation Act, land purchased after 1895 fell under State appropriation rights in which individuals had to file water claims and obtain permits from the State to divert water. Essentially, this created a first-come, first-served system because overappropriation of water hurt those who filed late for particular water rights (Stubbs and others, 2003). In the 1950s, the courts decided that the old “riparian water rights,” granted by the Spanish Crown or Mexico, were invalid. Additionally, water use from a shared borderland resource such as the Rio Grande involves complex international cooperation (e.g., Patiño-Gomez and others, 2007).

Today, water in Texas falls under a State licensing system that resulted from the 1969 lawsuit *State of Texas* v. *Hidalgo County Water Control and Improvement District No. 18*, often called the Lower Rio Grande Valley Water Suit, which established the water-rights system now used in the LRGV (Stubbs and others, 2003). Under this system, “Domestic, Municipal, and Industrial rights have the highest priority in the allocation procedures, with irrigation rights holding a residual claim on inflows to the reservoirs” (Characklis and others, 1999; Stubbs and others, 2003, p. 17; Levine, 2007), and water can be marketed by willing sellers (e.g., Schoolmaster, 1991; Wurbs, 1995). There are two types of irrigation rights: Class A and Class B. Class A irrigation rights are given to those that had proven water rights under the provisions of an old system, and Class B rights are given to those who can prove a history of diversion from the Rio Grande (Stubbs and others, 2003). During dry years, Class A water rights receive a greater allocation of water than those provided under Class B rights (Stubbs and others, 2003). The Lower Rio Grande Valley NWR has Class A and B water rights, but if water is scarce, allocations may be curtailed, making water shortages an issue for conservation of habitats such as rare flood-plain riparian forests. Although the legal settlement in 1969 attempted to fix problems with water allocation, water in the LRGV is still often overallocated, which can create conflicts among users (Stubbs and others, 2003) and even an uncertain international future as human populations and needs grow (Schmandt, 2002).

Detrimental Effects of Water Development on LRGV Biota

Modifications along the lower Rio Grande have vastly changed its flow and thereby altered native plant communities. The naturally occurring high- and low-flood periods that once characterized the lower Rio Grande have been eliminated or greatly reduced in frequency and duration, which has resulted in severe modification of its riparian corridor (Small and others, 2009). From the time Falcon Dam was completed in 1954 through 2004, mean annual flow of the Rio Grande past Brownsville, Tex., decreased 75 percent from 105.3 cubic meters per second (m^3/s) before completion of the dam to 25.77 m^3/s; similar declines were noted for daily event frequency: high-flow pulse, 28.3 percent before vs. 10.4 percent after; small flood, 14.5 percent before vs. zero after; and large flood, 4.9 percent before vs. zero after (Small and others, 2009). Major floods still occur and overtop the bank of the lower Rio Grande—sometimes with considerable ecological and long-term damage. For example, major flooding resulted when ongoing storage of water at Falcon Dam (at or near capacity) coincided with Hurricane Alex, causing the IBWC to release massive amounts of water from July through November 2010. Water breeched many levees, leaving Santa Ana NWR and 6,819 ha (16,850 acres) of river tracts in the Lower Rio Grande Valley NWR impounded with water for 5–8 months. Riparian vegetation that has evolved with flood-pulse cycles is not generally adapted to long periods of standing water; many trees died, permitting significant invasion of exotic saltcedar (see “Exotic and Invasive Species” section below).

Mature bottomland riparian forests of the lower Rio Grande Delta are adapted to varying degrees of high- and low-water flow (Small and others, 2009). With the loss of this naturally occurring flood-pulse cycle, mature bottomland forests are no longer an easily sustainable or restorable habitat type in the LRGV. Even in Santa Ana NWR, which has been protected for decades, mature bottomland forests composed of Texas ebony, Mexican ash, cedar elm, and sugarberry are changing from riparian bottomlands that evolved with regular sheet flooding to habitats able to tolerate extended dry periods (Small and others, 2009). Comparisons of studies conducted at Santa Ana NWR during the 1970s (Gehlbach, 1987) and 1990s (Brush and Cantu, 1998) show how remarkably disparate the forest types in the riparian zone became after just 30 years (Small and others, 2009). In the 1970s, a mature closed-canopy forest existed, with large-trunked trees and low densities (Gehlbach, 1987). Die-offs stemming from loss of the natural flood-pulse cycle left a vastly different forest by the 1990s, with a broken, not closed, canopy; canopy height decreased by 10 m (33 ft) in the riparian zone, stem densities of trees increased by 250 percent since the 1970s, and trunk diameters of individual trees decreased substantially (Brush and Cantu, 1998; Small and others, 2009).

“Riparian-dependent birds have been negatively impacted by habitat loss and severe deterioration of this habitat, over the past half century” (Rupert and Brush, 2006, p. 48), directly associated with the construction of Falcon Dam and other water-control activities that have severely reduced flooding along the Rio Grande (Small and others, 2009). The tall and mature riparian forests that once lined the Rio Grande and adjacent waterways no longer occur or have suffered severe die-offs because of the lack of flooding (Brush, 2005; Rupert and Brush, 2006). Riparian-dependent bird species that were reported as common in the 1870s either no longer occur in the LRGV or have become very rare (Sennett, 1879; Brush, 2005; Rupert and Brush, 2006). Some species like the *Geothlypis poliocephala* (gray-crowned yellowthroat) and *Icteria virens* (yellow-breasted chat), for example, have almost completely disappeared as breeding species in the LRGV (Brush, 2005; Rupert and Brush, 2006). Other once-abundant riparian species like the Audubon's oriole, red-billed pigeon, and tropical parula have become very rare and only occur in scattered locales where some mature riparian forests remain; these species can still be seen upriver near Falcon Dam where some elements of the historical flood-pulse cycle still occur (Brush, 2005; Rupert and Brush, 2006).

Although missing some of the mature riparian-forest-obligate avian species mentioned above, even depauperate riparian forest in tracts of the Lower Rio Grande Valley NWR can support higher avian richness and nesting densities than comparable upland tracts (Rupert and Brush, 2006). Unfortunately, the prevailing trend on many tracts in the Lower Rio Grande Valley NWR is that without restoration of some flooding, riparian forests will continue to become thorn forests that lack tall canopy trees (Brush and Cantu, 1998; Rupert and Brush, 2006). If this trend continues, there will be continued loss of riparian-dependent bird species in the LRGV. Some evidence suggests that large and wide riparian corridors can support more bird species at higher densities, raising the possibility that some loss from the drying of riparian areas can be offset if more land can be used to widen and expand riparian corridors (Rupert and Brush, 2006; Brush and Feria, 2015).

Native freshwater fish communities in the lowest reaches of the Rio Grande suffer from detrimental effects of flow alterations, increasing estuarine conditions, contaminants from industry and agriculture, and introduction of exotic, often invasive, fish and plant species (Contreras-Balderas and Lozano-Vilano, 1994; Contreras-Balderas and others, 2002; Tunnell, 2002d; Small and others, 2009; Martin and others, 2010). The lower Rio Grande and its delta have changed substantially in the past 50–60 years (e.g., Cooper and Wagner, 2013) to the point that unless flows are very high after heavy rain, little (if any) freshwater reaches the delta, being held by Amistad and Falcon Reservoirs and used for agriculture, municipalities, and industry in the LRGV (Small and others, 2009). The broad agricultural and urbanized deltaic plain is mostly drained into the Lower Laguna Madre by an artificial network that delivers water to the channelized, dredged, and variously impounded (small dams/diversions) Arroyo Colorado and North Floodway in Texas and South Floodway in Tamaulipas, Mexico (Tunnell, 2002a, 2002c; fig. 19). Under current low-flow conditions, and aside from limited rainwater runoff, little freshwater now reaches the lower Rio Grande, resulting in a negative freshwater inflow into the Lower Laguna Madre of -93×10^6 cubic meters per year (Tolan, 2013) and upstream advancement of estuarine conditions. The delta was formerly shallow water of the southern Lower Laguna Madre in Texas and the northern Laguna Madre de Tamaulipas in Mexico, but it is now a 1,550-km^2 bulge of "meander streams, oxbow lakes (resacas), playa lakes, wetlands, mudflats, lomas, and clay dunes" that effectively separates the two international lagoons (Tunnell, 2002b, p. 31).

If the long-gone, flood-pulse cycles of the Rio Grande cannot be mimicked by returning some aspects of the seasonal hydrologic regime (e.g., timing, duration, and extent), management activities such as land acquisition efforts of the Lower Rio Grande Valley NWR could have little effect on maintaining riparian-dependent wildlife diversity because deterioration of mature riparian forests will continue (Small and others, 2009). Although returning even some level of the flood-pulse cycle is a difficult prospect, especially considering the wide and varied stakeholders involved in the LRGV (including two different countries with different priorities), other major river systems, including the Colorado River system in Arizona, have achieved some level of success in this endeavor (e.g., U.S. Department of Interior, Bureau of Reclamation, 2001; Small and others, 2009).

Exotic and Invasive Species

Natural barriers (e.g., oceans and mountain ranges) and species-specific capabilities typically impede the spread of species beyond areas where they evolved, but humans have altered that. Exotic (or nonnative), invasive species—those that seriously affect populations of native species—threaten biodiversity, economic development, and human health (Lowe and others, 2004; Pimentel and others, 2005). Native species are often outcompeted or killed by invasive species; in fact, competition with invasive species is often cited as a principal reason for declines of many species now considered threatened and endangered, second only to habitat loss (Lowe and others, 2004; Pimentel and others, 2005). About 42 percent of threatened and endangered species in the United States are imperiled in some way by invasive species, and closer to 80 percent are imperiled elsewhere in the world (Pimentel and others, 2005).

All native aquatic and terrestrial habitats in the LRGV are affected to some degree by exotic species (e.g., Williams and Baruch, 2000; Smith, 2010; Mendoza and others, 2011). Exotic plant species, in particular, pose serious threats to the ecological integrity of biotic communities in the LRGV. Twelve grass species, 11 of which are exotic and 3 of which are priority target species for control, and 6 exotic woody plant species, 4 of which are priority target species, are variously invasive in the LRGV (table 10). Nine percent of the "100 of the World's Worst Invasive Alien Species" as listed by the Invasive Species Specialist Group of the World Conservation Union occur in the LRGV: 1 aquatic plant, 4 land plants, 2 fish, and 2 mammals (Lowe and others, 2004).

Table 10. Exotic and native invasive terrestrial grasses and woody plant species in the South Texas Refuge Complex of the Lower Rio Grande Valley.

Grass species	Origin
Arundo donax (giant reed)[a]	Mediterranean
Bothriochloa ischaemum var. *ischaemum* (King Ranch bluestem)	Europe/Asia
Cenchrus ciliaris (buffelgrass)[b]	dry eastern–southeastern Africa
Cynodon dactylon (Bermuda grass)	Asia (probable)
Dichanthium annulatum (Kleberg bluestem)[b]	Africa/Asia
Dichanthium aristatum (Angelton bluestem)	India
Echinochloa crus-galli (barnyard grass)	tropical Asia
Megathyrsus maximus (guineagrass)[b]	tropical/subtropical Africa
Melinis repens (natal grass)	tropical/subtropical Africa
Panicum antidotale (blue panicum)	Himalayas
Sorghum halepense (Johnson grass)	Mediterranean northern Africa
Urochloa platyphylla (broadleaf signalgrass)	southeastern–southern United States
Woody plant species	**Origin**
Leucaena leucocephala (lead tree)	southern Mexico/Central America
Melia azedarach (chinaberry)[b]	southeastern Asia/Australia
Prosopis glandulosa var. *glandulosa* (honey mesquite)[a]	southwestern United States/ Mexico
Schinus terebinthifolius (Brazilian pepper)[a,b]	tropical/subtropical South America
Tamarix aphylla (athel tamarisk)	eastern–central Africa to western–southern Asia
Tamarix ramosissima (saltcedar)[a,b]	Europe/Asia
Triadica sebifera (Chinese tallow)[b]	eastern Asia
Aquatic plant species	**Origin**
Eichhornia crassipes (water hyacinth)[a]	South America
Hydrilla verticillata (hydrilla)	southeastern Asia

[a]Listed among the 100 worst invasive species globally (Lowe and others, 2004).

[b]Priority target species for control/eradication in the South Texas Refuge Complex.

Plants

Water Hyacinth

Eichhornia crassipes (water hyacinth) is an aquatic plant native to South America (Lowe and others, 2004). Its large purple flowers make it popular in ornamental plantings, and as such, it is now found in more than 50 countries on five continents (Lowe and others, 2004). Water hyacinth can become invasive very quickly, doubling its biomass in as little as 5 days. It is detrimental to native plants and wildlife and forms vast mats covering once open waterways, rendering them unfit for boating, swimming, and fishing. Mats of water hyacinth prevent light and oxygen from diffusing into the water column, which can cause die-offs in native plants and animals (Lowe and others, 2004). Water hyacinth occurs in the LRGV, with some attempts at biological control (Grodowitz and others, 2000), but currently not in the STRC.

Hydrilla

Hydrilla verticillata (hydrilla), native to Southeast Asia, is an aquatic plant often sold for use in aquaria and first discovered in the wild in the United States in Florida in the 1960s. It is a major threat to native aquatic ecosystems (Owens and others, 2005) because it grows rapidly, blocks sunlight in the water column, depletes oxygen, and causes massive die-offs of native plant and animal species. Waterways choked with hydrilla are not suitable for fishing, boating, and swimming and can cause mechanical and system-maintenance problems during water treatment, hydroelectric power generation, and water delivery (Grodowitz and others, 2000; Owens and others, 2005; Douglas, 2009). It was first reported in the LRGV in 1990 near Brownsville, Tex., and now occurs beyond Falcon Reservoir (Owens and others, 2005), with some attempts at biological control (Grodowitz and others, 2000), but not in the STRC.

Giant Reed

Arundo donax (giant reed) is a large invasive grass that occurs in dense, extensive stands up to 6 m (12 ft) high along the lower Rio Grande (fig. 20*A*), including the LRGV (Owens and others, 2005; Seawright, Rister, Lacewell, McCorkle, and others, 2009; Seawright, Rister, Lacewell, Sturdivant, and others, 2009). Giant reed displaces native plant species, forms dense monocultures in riparian areas and other wetland habitats, and transpires large amounts of water (Owens and others, 2005; Seawright, Rister, Lacewell, McCorkle, and others, 2009). Current research in the LRGV is exploring possible biological control agents (e.g., *Tetramesa romana*

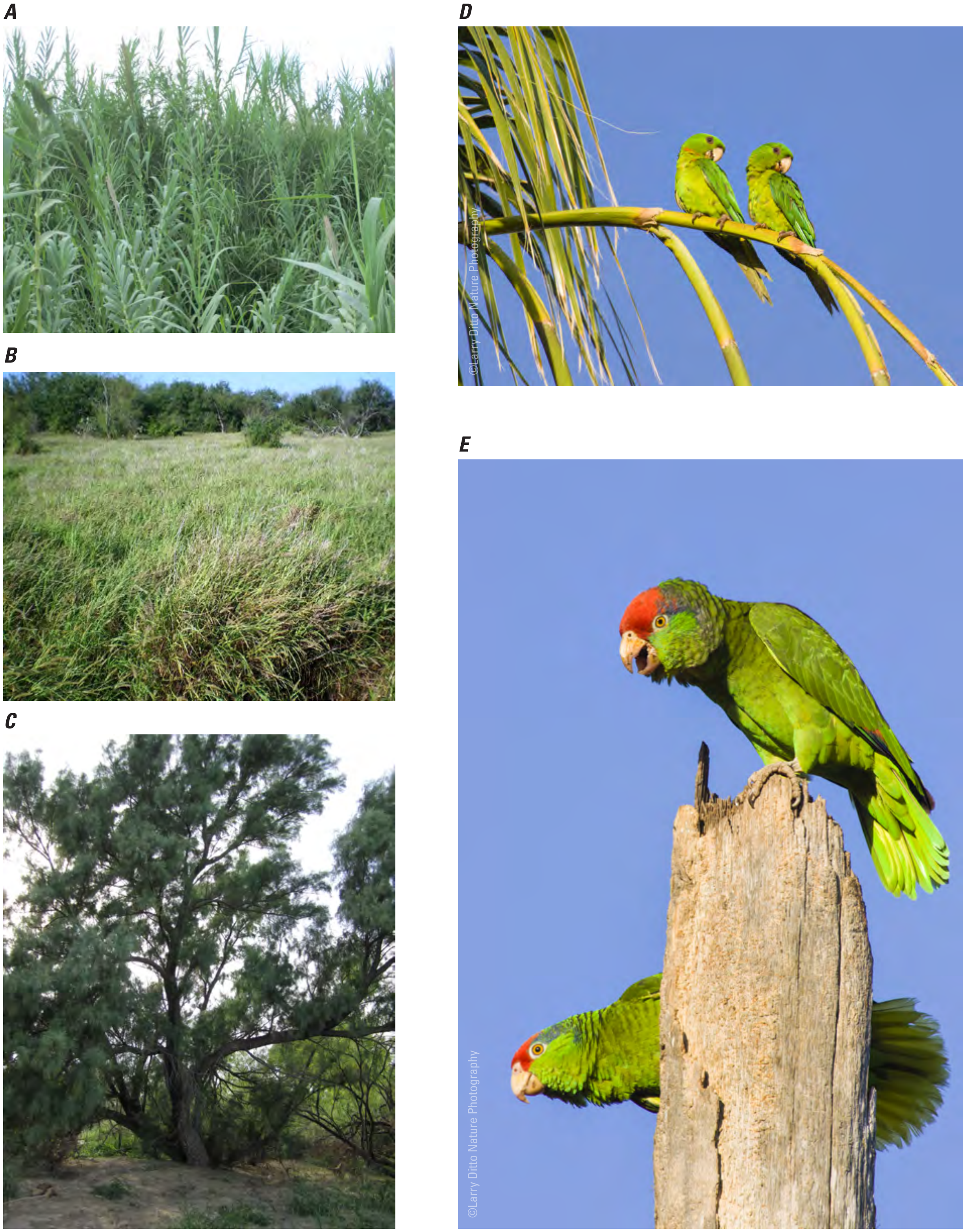


Figure 20. Invasive and (or) nonnative plant and animal species that challenge conservation efforts in the Lower Rio Grande Valley: *A*, *Arundo donax* (giant reed); *B*, *Cenchrus ciliaris* (buffelgrass); *C*, *Tamarix aphylla* (athel tamarisk); *D*, *Aratinga holochlora* (green parakeet); and *E*, *Amazona viridigenalis* (red-crowned parrot). Photographs on the left courtesy of Kim Wahl, U.S. Fish and Wildlife Service; photographs on the right, ©Larry Ditto Nature Photography, used with permission.

[galling wasp], *Rhizaspidiotus donacis* [arundo scale], and *Lasioptera donacis* [arundo gall midge]) that might be used to reduce giant reed (e.g., Goolsby and Moran, 2009; Seawright, Rister, Lacewell, McCorkle, and others, 2009; Seawright, Rister, Lacewell, Sturdivant, and others, 2009; Moran and Goolsby, 2010; Poinar and Thomas, 2014). In June 2015, the Governor of Texas signed a bill directing the Texas State Soil and Water Conservation Board to develop a program to eradicate giant reed along the Rio Grande (K. Wahl, pers. commun.).

Buffelgrass

Buffelgrass is a perennial warm-season bunchgrass that was widely planted to revitalize overgrazed areas, particularly in semiarid Australia and the southwestern United States (Jackson, 2005; Flanders and others, 2006; fig. 20*B*). Buffelgrass often displaces native herbaceous species, simplifying a plant community (Jackson, 2005; Flanders and others, 2006; Abella and others, 2012). Loss of plant diversity can cause a trophic cascade, decreasing invertebrate diversity with eventual loss of vertebrates dependent on them; areas dominated by buffelgrass have lower diversity of plants and lower abundance of breeding birds, particularly those that feed on or near the ground (Flanders and others, 2006). Buffelgrass grows in dense monocultures on drier tracts of the Lower Rio Grande Valley NWR (fig. 20*B*), resulting in direct competition for space and light and allelopathic effects (Hussain and others, 2011) and poor conditions for restoration of native species (Abella and others, 2012). A dense canopy of native plants can shade out buffelgrass, but much of that has been lost to brush clearing and livestock grazing.

Guineagrass

Guineagrass is particularly invasive, and like other introduced African grasses, it creates dense monocultures, especially in disturbed areas, that displace native plant species and lead to impoverished native systems (Smith, 2010). Guineagrass can persist during dry periods. As with giant reed and buffelgrass, monocultures of guineagrass can build up large amounts of biomass, causing fire hazards. When guineagrass stands burn, high levels of biomass create intense fires detrimental to native plants not adapted to fire, further enhancing encroachment of guineagrass. In the LRGV, guineagrass often colonizes wet lowland areas, in contrast to buffelgrass that is typically found in dry upland areas. Both grasses cause problems for restoration of native plants because they can quickly take over a site (Jackson, 2005; Smith, 2010), making control and restoration difficult.

Saltcedar

Three exotic species of *Tamarix*—a Eurasian genus of considerable variation—are found in the LRGV: *Tamarix aphylla* (athel tamarisk, fig. 20*C*), a large tree capable of growing to about 18 m (about 60 ft) high, and two shrubby forms, the most invasive *T. ramosissima* (saltcedar; table 10) and *T. canariensis* (Canary Island tamarisk). Particularly stress tolerant, saltcedar can be highly invasive in riparian corridors of dry-country streams and other waterways, and it often forms dense monocultures that alter and decrease flows in areas that have already been altered by dams, water diversions, etc. (Glenn and Nagler, 2005; Douglas, 2009). In the LRGV, it is established along the Rio Grande, canals, and resacas and has spread into upland areas around stock ponds and culverts. Considerable effort has been focused on trying to mechanically and biologically control or eradicate species of *Tamarix* in the western United States because of early conclusions that they were “water-wasting foreign monsters” (Chew, 2009, p. 231); however, recent publications suggest that perceptions might be changing and that species of *Tamarix* might play roles in riparian stabilization and provide useful avian habitat in riparian areas (Sogge and others, 2008; Stromberg and others, 2009; Paxton and others, 2011). Nevertheless, the highly invasive and dominant tendencies of species of *Tamarix* were expressed after Hurricane Alex in 2010, when athel tamarisk and saltcedar, in particular, proliferated extensively on disturbed sites in the LRGV.

Animals

Red Imported Fire Ant

Solenopsis invicta (red imported fire ants) were accidently introduced into the United States in Alabama in the late 1930s. They rapidly spread across most of the southern United States and were found in potted plants at a Brownsville, Tex., nursery in 1991 (Allen and others, 1993) at the western edge of their aridity tolerance (LeBrun and others, 2012). Red imported fire ants can damage agricultural crops such as citrus, kill newborn livestock and ground-dwelling wildlife, and decrease biodiversity of invertebrates (Allen and others, 1998; Wojcik and others, 2001). In central Texas, exclusion of red imported fire ants increased nest survival of two *Vireo* spp. (vireo) by 86–210 percent (Campomizzi and others, 2009). Red imported fire ants variously affect native ants, depending in part on soil moisture. Red imported fire ants reduce overall ant diversity in undisturbed wet areas but have a weaker effect in disturbed dry areas, and controlled burning reduces abundance of red imported fire ants (LeBrun and others, 2012). Concern has been expressed about the loss of certain ant species caused by red imported fire ants relative to dietary requirements of the State-threatened *Phrynosoma cornutum* (Texas horned lizard), but differential aridity tolerances might minimize this interaction.

Africanized Honey Bee

All *Apis mellifera* (honey bees) in the Americas are exotic, introduced by humans from the Old World—Europe in most of the United States and Canada. European honey bees did not do well in tropical Central and South America, and honey production was poor; therefore, an African subspecies (*scutellata*), better adapted to the tropical conditions, was introduced near Sao Paulo, Brazil, in 1956 (Winston, 1992). Since then, Africanized honey bees have spread rapidly, up to 300–500 kilometers per year, and reached very high densities in some areas (Winston, 1992). Absent in the LRGV in the late 1980s (Rubink and others, 1990), the first Africanized honey bees seen in the United States were caught in Hidalgo County in the LRGV in 1990 (Kaplan, 1990; Winston, 1992). Mitochondrial haplotypes of honey bees in southern Texas now show that the maternal origin of most colonies is from Africanized honey bees (Pinto and others, 2004). Unfortunately, Africanized honey bees show exceptionally high levels of defensive behavior, with large attacks and massive stinging after minimal disturbance (Winston, 1992).

Exotic or Naturalized Birds

Introduced *Columba livia* (rock pigeons) and more recently *Streptopelia decaocto* (Eurasian collared-doves) thrive in urban areas of the LRGV (Brush, 2008b). Eurasian collared doves were first seen in the LRGV in 1998 (Brush, 2005, 2008a) and are of concern due to their explosive population patterns as they spread from release sites in Florida in the late 1970s, and their potential to outcompete native doves (Poling and Hayslette, 2006). Two parrots, *Aratinga holochlora* (green parakeet; fig. 20*D*) and the *Amazona viridigenalis* (red-crowned parrot; fig. 20*E*), are now common in urban areas of the LRGV (Butler, 2005). Nevertheless, there are no historical records to suggest that they were ever native in the LRGV. The TPWD considers the red-crowned parrot an indigenous species, subject to protection under Texas law (Shackelford and Hanks, 2016). Because both parrots have parts of their breeding distributions in northern Tamaulipas, Mexico, not far from the LRGV (Enkerlin-Hoeflich and Hogan, 1997; Howell and Webb, 1995; Brush, 2009a), some have speculated about natural range extension; alternatively, both species have been sold in the pet trade, so those in the LRGV could be escapees or have been deliberately released (Brush, 2005; Rappole and others, 2007). Urban settings benefit both species by providing dependable sources of food (e.g., acorns, figs, and palm fruits) and safe nesting sites (Brush, 2005). The red-crowned parrot is listed as endangered by the IUCN and as a foreign candidate species by the USFWS. Serious declines in numbers of red-crowned parrots in Tamaulipas, Mexico, because of the pet trade and destruction of native habitats (Enkerlin-Hoeflich and Hogan, 1997) could mean that relatively new populations in the LRGV could have a role in their future conservation (Brush, 2005).

Exotic Mammals

Free-ranging nilgai—native to India and marginally Pakistan and Nepal, and introduced in Texas in the 1930s (Leslie, 2008)—occur in Cameron, Hidalgo, and Willacy Counties after having escaped from ranches north of the LRGV. Although Schmidly (2004, p. 285) stated that the nilgai "does not appear to harm native species," its spread into the LRGV, particularly in areas that support the northern ocelot and perhaps the Gulf Coast jaguarundi, is of concern because heavily used nilgai trails might alter dense shrubby habitats that are critical to these endangered felids (Leslie, 2008). Because of the possibility of transmission of tickborne blood parasites from Mexico to United States cattle via nilgai, the U.S. Department of Agriculture routinely samples nilgai in the Boca Chica tract in the Lower Rio Grande Valley NWR and the Bahia Grande tract in Laguna Atascosa NWR. Although native, *Odocoileus virginianus* (white-tailed deer) also plays a role in dispersal and maintenance of infected ticks in the LRGV (Pound and others, 2010). Such parasites transmit tick fever, fatal to cattle, and detection has resulted in a permanent and expanding quarantine zone of 2,233 km^2 (862 mi^2) along the lower Rio Grande in the LRGV.

Domestic pigs are a variant of *Sus scrofa* (Eurasian wild pig) and were first introduced in the United States in Florida in 1539 (Wood and Barrett, 1979). Introductions continued in the southeastern United States, particularly from the Carolinas west to Texas. Over time, pigs escaped, often tended in free-ranging groups, and became feral. Feral pigs reproduce quickly, spread rapidly, damage native habitats, are highly omnivorous, compete with or eat native wildlife, and cause up to $52 million per year in damage to agricultural crops (Wood and Barrett, 1979; Taylor and others, 1998; Timmons and others, 2012). Terrestrial vertebrates ranging from salamanders to birds and small mammals (and their nests) have been found in stomachs of feral pigs (Wood and Barrett, 1979). In southern Texas, it is possible that feral pigs compete with white-tailed deer and *Pecari tajacu* (collared peccaries—Taylor and others, 1998). More than a million feral pigs occurred in Texas by the early 1990s (Taylor, 1991). As with nilgai, populations of feral pigs are established in the LRGV and are actively controlled in the STRC with permits to professional trappers and sportsmen during designated hunting periods, with unlimited harvest. Regular drought may be a key reason why domestic pig populations have not "exploded" in the LRGV (B.R. Winton, pers. commun.)

Climate Change

In 2001, the Union of Concerned Scientists and the Ecological Society of America provided a comprehensive synthesis of climate-related challenges facing the gulf coastal region of the United States (Twilley and others, 2001). Key among them is sea-level rise, which is projected to be more dramatic in Gulf Coast States than elsewhere because of local shoreline erosion and land subsidence, caused by groundwater withdrawal and oil and gas production, which decrease pore pressures in underlying sediments, causing land to sink (Montagna and others, 2011). Globally, sea levels have risen 10.2–20.3 cm (4–8 inches) over the past 100 years compared to 20.3–101.6 cm (8–40 inches) throughout the gulf coastal region (Twilley and others, 2001). With the same 100-year horizon, Schmandt (2011, p. 257) concluded that "temperatures [in Texas] will rise, heat waves will occur more frequently, it will be drier west of the Interstate 35 corridor, severe weather will become more frequent, in-stream flows will fall, biodiversity will decline, and the sea level will rise." All of these events will be accompanied by increases in flooding, heat-related illnesses, ground-level-ozone-caused respiratory diseases, and harmful algal blooms (Schmandt, 2011; Schmandt and others, 2011).

In southern Texas, increases in sea level and sea temperatures are already part of the historical record; for example, "sea-level rise along the South Texas coast is caused by natural and human-induced land surface subsidence and a global rise in ocean level, … sea level has risen 2.05 millimeters (0.08 inches) per year at Port Mansfield since 1963 and 3.44 millimeters (0.14 inches) per year at South Padre Island since 1958, [and] after estimates for local land subsidence are added, the amount of projected relative sea level rise by the year 2100 is 0.2–0.61 meters (0.66–2 feet) at Port Mansfield and 0.34–0.75 meters (1.1–2.5 feet) at South Padre Island" (Montagna and others, 2011, p. 102–103). Sea-level rise could substantially change the character of the coastal LRGV, but changes could be slow and perhaps easily overlooked. As sea levels rise, tidal flats and seagrass meadows could initially decrease as they respond to increasing water depth and then, if conditions permit, slowly advance toward newly inundated land (Montagna and others, 2007). Some of these changes have already taken place; from the 1950s to 2004, tidal flats decreased from 13,647 ha (33,722 acres) to 6,121 ha (15,125 acres), but seagrass meadows increased from 4,167 ha (10,297 acres) to 8,398 ha (20,752 acres) in the Texas Coastal Bend (table 3 in Montagna and others, 2007).

Generally, climate change will cause a northward advancement of the tropical temperature zone, with associated biotic, but at present difficult-to-predict, changes (Brennan, 2007; Norwine and John, 2007; North, 2011; Fitzpatrick and others, 2013). Rappole and others (2007) assessed changes in distributions of tropical, subtropical, and warm-desert bird species and concluded that at least 70 species have already expanded their breeding ranges northward and eastward into, within, and beyond southern Texas—many moving into temperate grassland and forested habitats. Although specific correlative data were lacking, increasing mean annual temperature was hypothesized to be responsible; many species moved into areas where availability of preferred habitats was declining (Rappole and others, 2007). From a wildlife standpoint, species dependent on high-latitude habitats could suffer the most under a planetary warming scenario, but vigilance over the long term could be necessary everywhere to identify and respond appropriately to likely species-specific and localized conservation challenges as they arise (Root and Schneider, 2002; Schneider and Root, 2002; Inkley and others, 2004; Brennan, 2007).

The remarkable diversity of butterflies in the LRGV (table 7) could be used to establish methods to monitor long-term effects of climate change because populations of terrestrial invertebrates such as butterflies, with very short generation times, quickly respond to subtle changes in climate, particularly those that affect their interactions with other species such as plants on which they depend (Crozier, 2002; Hellman, 2002). Beginning in the late 1960s and correlated with warming temperatures, the *Atalopedes campestris* (Sachem grass skipper), which also occurs in the LRGV, expanded its distribution northward by about 700 km (435 mi) from its historical distribution in California as far north as south-central Washington by 1998 (Crozier, 2002). The Sachem grass skipper is in the most speciose butterfly family (Hesperiidae), with 111 skipper species in LRGV (table 7), and populations of the most common among them could be monitored to provide a long-term record of association with climate change, perhaps efficiently and inexpensively.

Border Issues and Homeland Security

Humans have crossed the Rio Grande for millennia. Prior to European arrival and settlement, Coahuiltecan Native Americans camped up and down the lower Rio Grande in what is the present day LRGV (Thompson, 1997). After Mexican and Spanish colonization in the 16th century, people established settlements on both sides of the lower Rio Grande. Crossing the river became a growing obstacle when the Rio Grande became the official border between the United States and Mexico after the Mexican-American War in the 1850s. Many people have crossed the Rio Grande illegally since the 1850s, moving contraband, notably during the American Civil War, the Mexican Revolution, and Prohibition in the United States (Thompson, 1997).

Security of the current United States-Mexico border was relatively relaxed from the mid-1800s until 1993 when the United States instituted a major policy shift to enhance enforcement and minimize illegal border crossings and associated illegal activities (Cornelius, 2001; Parcher and Page, 2013). Informal and underground illegal activities are now common along the southern Texas border, perpetuated in general by a large gap in wages between Mexico and the United States (Dávila and others, 2002). Ongoing illegal activities, recently ranked by their potential to generate income, were drug dealing, human trafficking, dog and cock fighting, prostitution, gambling, and stealing and selling pirated or counterfeited goods and services (Richardson and Pisani, 2012). The U.S. Customs and Border Protection (CBP) routinely intercepts drugs, primarily marijuana and cocaine but also heroine and methamphetamines, at international bridges and on United States land adjacent to the Rio Grande.

Border-security activities are usually most intense in and around centers of human activity, so the rapidly growing cities of McAllen, Brownsville, and Harlingen, Tex., have experienced substantial change with regard to security issues. Presence of border patrol in the LRGV increased 633 percent from 418 agents in 1992 to 3,064 agents in 2014 (U.S. Customs and Border Protection, 2015). More border patrol agents mean more motor vehicles, all-terrain vehicles, horse patrols, helicopters, boats, camera towers, lights, and other forms of surveillance tools. There is ever-growing pressure to accommodate these agents and their equipment on tracts of the Lower Rio Grande Valley NWR, where isolated remnants of native vegetation provide cover for illegal activities.

Through the 1980s and 1990s, border-patrol activities deterred illegal immigration and other illegal activities in the short term but had "non-existent" effects in the long-term (Dávila and others, 2002, p. 459). As a result, in part, the United States passed the Secure Fence Act (Public Law 109–367) in 2006. The idea of a fence evolved into border obstructions of concrete walls, 6-m-high (20-ft high) steel fences, and (or) earthen levees (Abhat, 2011; fig. 21). The border fence in the LRGV is only one part in about 1,127 km (700 mi) built along the 3,141-km (1,952-mi) United States-Mexico border. At least 36 Federal environmental and cultural laws were waived to allow rapid construction of the border fence (Urreiztieta and Harris, 2011). In the LRGV, 18 of a proposed 21 segments have been built, with the longest segment of 21 km (13.1 mi) in Brownsville, Tex., in Cameron County. There are 56 km (35 mi) of border fence in Cameron County, 35 km (22 mi) in Hidalgo County, and 21 km (13 mi) planned in Starr County but currently not completed.

Segments of the border fence in Cameron County were built on the north side of the IBWC flood-control levee and outside of the flood plain. Inside the IBWC flood-control levee, known as the restricted use zone, no development is allowed because it would affect flood control. Segments of the border fence in Cameron County were built with 21.6- by 28-cm (8.5- by 11-inches) openings every 0.4 km (0.25 mi) to facilitate wildlife being able to move north of the fenced areas. Wildlife (e.g., Texas tortoises and coyotes) have used these openings. The border fence in Hidalgo County was built on the south side of the IBWC levee and inside the flood plain because it could satisfy flood-control requirements of U.S. Federal Emergency Management Agency. Segments of the border fence in Hidalgo County have about 5 m (16 ft) of concrete from the ground up and steel fence on top (fig. 21). These segments do not have openings and serve as true barriers to movements of nonvolant animals and will likely be most pernicious to sensitive and rare species such as northern ocelots and Texas tortoises.

Numbers of roads in the LRGV have increased substantially to provide access to the border fence and surveillance along the border. Many of these roads traverse important tracts of the Lower Rio Grande Valley NWR, some directly along the Rio Grande, and resulted in the loss of native habitat when vegetation was cleared to build the roads and enhance surveillance. These activities have created fragmentation of habitats critical to native wildlife, directly conflicting with the conservation mission of the Lower Rio Grande Valley NWR. The border fence isolated already fragmented tracts in the Lower Rio Grande Valley NWR, making it hard for refuge personnel to access them for monitoring and other management activities such as habitat restoration.

Numbers of apprehensions of unauthorized immigrants on the United States-Mexico border in 2014 were as low as they have been since the mid-1970s; proportions of Mexican nationals apprehended fell to historic lows and, for the first time on record, were less than proportions of non-Mexico apprehensions (Krogstad and Passel, 2014). Such improvements have not come without conservation costs. The border fence now covers much of the length of the LRGV, albeit in intermittent segments, from Peñitas, Tex., to Brownsville, Tex., (some small sections in Starr County are yet to be completed). In many areas, sections of the fence are ≥4 m (13 ft) high and have vehicle barriers and barbed wire. Fence segments often have cleared vegetation and roads ≥25 m (82 ft) wide (e.g., Flesch and others, 2009), creating a substantial gap between native habitats over wide stretches of the United States-Mexico border (fig. 21).

Construction of roads in forested habitats increases habitat fragmentation, and multiple studies show that even small amounts of habitat fragmentation increase edge habitat, which can adversely affect certain bird species (e.g., Askins and others, 1990; Askins, 1994; Paton, 1994; Ortega and Capen, 1999). Even small increases in edge habitat can lead to increased nest predation and parasitism by cowbirds (Ortega and Capen, 1999). For example, fragmentation and perhaps subsequent increases in cowbird parasitism have been linked with the decline of the Audubon's oriole, one of the high-profile bird species in the LRGV (e.g., Brush, 2005). Increased traffic along the border-patrol roads could have negative effects on other species of wildlife, such as the endangered northern ocelot, either through direct mortality or through disruption of their normal activities.

Flesch and others (2009) hypothesized that the new obstructions along the United States-Mexico border could become a substantial barrier to wildlife movements. They demonstrated that dispersal and movements of *Glaucidium brasilianum* (ferruginous pygmy-owls) in Arizona were impeded by large gaps in native vegetation on either side of the border fence, and with enhanced disturbance, these habitat gaps resulted in a lower rate of successful colonization. Ferruginous pygmy-owls typically fly lower than the height of the border fence, and effects of habitat gaps and disturbance were particularly disruptive to juvenile owls (Flesch and others, 2009). This species occurs in the LRGV and is listed as threatened in Texas. In the LRGV, the border fence could similarly affect endangered northern ocelots and Gulf Coast jaguarundi, as well as even more common bobcats, coyotes, and white-tailed deer (e.g., Bies, 2007; Abhat, 2011).

Lasky and others (2011) conducted the most biogeographically comprehensive assessment of risks to

Figure 21. The border fence along the Lower Rio Grande Valley, which has been constructed in various ways and now extends in 18 of 21 proposed segments, currently totaling 91 kilometers (57 miles) in Cameron and Hidalgo Counties. Note that considerable brushland habitat, visible beyond the fence, was permanently lost during construction and to permit regular vehicular assess along the fences. Photographs courtesy of Chris Perez, U.S. Fish and Wildlife Service (top left and right), and Vince Cavalieri, U.S. Fish and Wildlife Service.

313 amphibian, reptile, and nonvolant mammal species affected by the fence along the United States-Mexico border. They found that 50 species and three subspecies, globally or federally threatened in the United States or Mexico, occur within 50 km of the border. The Gulf Coast fenced area, which was only represented in their analysis along the border by the LRGV, had 6 amphibians, 1 reptile, and 2 nonvolant mammals and was among 3 of 7 ecoregions of particular conservation concern along the entire border.

Conservation Opportunities for the LRGV in the 21st Century

Although the LRGV has experienced substantial alterations to its native habitats and continues to experience demands from an increasing human population, opportunities to enhance conservation in the LRGV still exist. Many of the international, Federal, State, local, and private partnerships that have helped conserve aspects of the unique biota of the LRGV are still in place and could be refocused on areas of immediate concern. For example, new corridors that connect native habitats critical to the endangered northern ocelot could enhance the entire conservation network of properties already conserved in the LRGV.

Productive Partnerships

Ecotourism and Conservation Activities

Wildlife-related recreation (i.e., hunting, fishing, and wildlife watching) is very popular in the United States, with more than 87 million people participating and spending about $122 billion in 2006 (U.S. Department of Interior, Fish and Wildlife Service, and U.S. Department of Commerce, 2007). Hunting and fishing have been historical mainstays of wildlife-related recreation in the United States, but in recent decades, wildlife watching, particularly bird watching, has become increasingly popular and now surpasses numbers of people involved in and economic contribution of consumptive hunting and fishing—both very popular in the LRGV (fig. 22). In 2006, 48 million bird watchers spent $36 billion on trips and equipment in the United States, which generated $82 billion in total direct and indirect industry output (Carver, 2009). There were 4.2 million bird watchers that spent $2.9 billion in Texas in 2006, which exceeded numbers participating in hunting (more than 1 million hunters spending $2.2 billion) and fishing (2.5 million anglers spending $3.2 billion—Mathis and Matisoff, 2004; U.S. Department of Interior, Fish and Wildlife Service, and U.S. Department of Commerce, 2007; Carver, 2009).

Nature tourism in the LRGV is a very important and rapidly growing sector of the economy, contributing $100–170 million annually in the early 2000s (Mathis and Matisoff, 2004; Mathis and others, 2004) to more than $300 million by 2011 (Woosnam and others, 2011). “Winter Texans” have long been part of the senior travel market to the LRGV, ranking the mild climate and friendliness of the people as the most important attractions in choosing their “winter home”; relative to the USFWS mission, 55 percent of visitors ranked wildlife refuges as important attractions in the LRGV, only behind visiting Mexico, beaches, and area zoos (tables 2 and 3 in Vincent and Santos, 1990; Crompton and others, 1992). Winter visitors ranked availability of “beautiful wildlife refuges” second only to “plentiful array of festivals” relative to the attractiveness of the LRGV (Fakeye and Crompton, 1991, p. 13).

Texas is often the number one state for bird watching, and the LRGV is often in the top 10 birding destinations in the United States (e.g., Mathis and Matisoff, 2004). With so many active bird watchers living in and visiting the LRGV and the popularity of the Rio Grande Valley Birding Festival (table 11)—held in November for the last 21 years—TPWD, in partnership with USFWS, nine valley municipalities, and other government agencies, initiated a plan to develop a World Birding Center in 1998 to “serve as the model for the future development and application of conservation, education, and economic growth” (Vincent and Thompson, 2002, p. 154). By 2005, the World Birding Center consisted of a central visitor facility at Bentsen Rio Grande Valley State Park, 2 gateway visitor facilities, 2 major interpretive areas, and 5 destination locations, located along 193 km (120 mi) of the LRGV. Initial assessments of community support and sustainability were positive (Vincent and Thompson, 2002), but it has become apparent more recently that many bird watchers—some from foreign countries—want to be outside looking for rare birds rather than inside visitor centers. As a result, some of the centers are no longer staffed by USFWS personnel (e.g., Roma Bluffs, formerly operated by the USFWS). Bird- and other wildlife-related festivals of 1 to several days long were estimated to contribute >$1 million to the local economy (Mathis and Matisoff, 2004).

The rich variety of terrestrial and aquatic plant and animal communities, outlined in the first part of this report, provides substantial attractions to residents and visitors to the LRGV. Various festivals to celebrate this diversity have been established through time, and numerous related activities and conservation groups are dedicated to enhance, preserve, and appreciate it (table 11). With more than 100 species of dragonflies and damselflies in the LRGV, it is not unexpected that a unique festival celebrates their late-spring peak abundance. During Dragonfly Days in Weslaco, Tex., species new to the LRGV, and even the entire United States, have been discovered; for example, the *Planiplax sanguiniventris* (Mexican scarlet-tail dragonfly), *Tauraphilia argo* (bow-tailed or arch-tipped glider), and *Anax concolor* (blue-spotted comet).

Abundance and exceptional diversity of butterflies in the LRGV (Wauer, 2004; table 7) led the North American Butterfly Association to establish the National Butterfly Center and open the International Butterfly Park. Both are located near Bentsen Rio Grande Valley State Park, along with the headquarters of the World Birding Center, and are dedicated to education, conservation, and scientific research on butterflies. The Texas Butterfly Festival, held annually for the last 20 years, increases tourism in mid-autumn (table 11), particularly to the National Butterfly Center and other areas offering butterfly-viewing opportunities (South Texas Chapter of the North American Butterfly Association, 2015). The Texas Butterfly Festival also increases interest in establishing butterfly gardens at schools and in public places in the LRGV, further fostering conservation. Ecotourists interested in butterflies are also drawn to Santa Ana NWR, Laguna Atascosa NWR, and private reserves that have developed gardens to attract the varied butterflies of the LRGV. If butterfly-related activities are continually highlighted by local, State, and Federal agencies and organizations and become part of regular public discourse in the LRGV, they could become as locally iconic as the monarch butterfly has become internationally (Gustafsson and others, 2015).

The Ocelot Conservation Day Festival has been held annually in March since 1997 and focuses on conservation of the endangered northern ocelot in the LRGV by providing educational presentations by experts, activities for children, and opportunities to see a live ocelot. Since 2007, the Cincinnati Zoo's Cat Ambassador Program has brought trained ocelots to the LRGV. The 1-day festival was initially held at the Marine Military Academy in Harlingen, Tex., but in recent years, it has been held and hosted by the Gladys Porter Zoo in Brownsville, Tex., and cohosted by Friends of Laguna Atascosa NWR and the USFWS. It has attracted more than 1,500 participants in recent years, and proceeds support important research and conservation of the northern ocelot in the LRGV.

Agency and Nongovernmental Organization Cooperation

Many State, Federal, and international agencies and nongovernmental organizations (NGOs) work cooperatively on common conservation objectives in the LRGV (table 11). The TPWD still owns and manages a number of areas in the LRGV to conserve native brush habitat and support hunting, particularly for white-winged doves, and the Lower Rio Grande Valley NWR now manages eight TPWD wildlife-management areas. The Las Palomas Wildlife Management Area consists of 1,340 ha (3,311 acres) in 18 units of 0.8–244 ha (2–604 acres), scattered throughout the LRGV, primarily in Cameron and Hidalgo Counties (Mathis and Matisoff, 2004). The TPWD continues to manage Bentsen Rio Grande Valley, Resaca de la Palma, and Estero Llano Grande State Parks in the LRGV.

Figure 22. Surf fishing (left) and birdwatching (right), just two examples of the diverse recreational opportunities in the Lower Rio Grande Valley. ©Larry Ditto Nature Photography, used with permission.

Table 11. Prominent annual festivals, activities, and locations related to wildlife and conservation in the four-county area of the Lower Rio Grande Valley in southern Texas.

[LRGV, Lower Rio Grande Valley; USFWS, U.S. Fish and Wildlife Service; NWR, national wildlife refuge]

Name	Purpose	Sponsor and (or) location	Related link (accessed April 2016)
	Festivals		
Ocelot Conservation Day Festival	Conservation of the endangered *Leopardus pardalis albescens* (northern ocelot) in the LRGV	Gladys Porter Zoo, Brownsville, and USFWS	www.fws.gov/refuge/laguna_atascosa/visit/visitor_activities/ocelot_conservation_day.html
Rio Grande Valley Birding Festival	Celebrating the renowned bird diversity in the LRGV	Harlingen	www.rgvbirdfest.com
Rio Reforestation	Annual public event focused on restoration of native habitats in the LRGV	USFWS	www.fws.gov/refuge/Lower_Rio_Grande_Valley/visitor_activities/special_events.html
Texas Butterfly Festival	Celebrating the great butterfly diversity in the LRGV	Mission	www.texasbutterflyfestival.com
Wild in Willacy	Natural biodiversity of Willacy County	Raymondville and Port Mansfield	www.wildinwillacy.com
	Related to conservation		
Anzalduas County Park	Outdoor recreation with opportunities for bird and butterfly watching	Mission	www.missiontexas.net/attractions/anzalduas-county-park and www.thedauphins.net/id103.html
Chihuahua Woods Preserve, The Nature Conservancy	Preservation of Tamaulipan thornscrub habitat and a unique community of cacti	Mission	www.nature.org/ourinitiatives/region/northamerica/unitedstates/texas/index.htm
Frontera Audubon Society	Dedicated to conserving native birds and habitats of the LRGV	Weslaco	www.fronteraaudubon.org
Friends of Laguna Atascosa National Wildlife Refuge	Enhance conservation and education at Laguna Atascosa NWR and operate visitor center store	Los Fresnos	http://friendsoflagunaatascosanationalwildliferefuge.org
Friends of the Wildlife Corridor	Enhance conservation and education at Santa Ana and Lower Rio Grande Valley NWRs and operate visitor center store at Santa Ana	Alamo	https://friendsofthewildlifecorridor.org
Gladys Porter Zoo	Animal display, conservation, and education	Brownsville	www.gpz.org
Hugh Ramsey Nature Park	Once a landfill now dedicated to habitat conservation and associated with Harlingen Arroyo Colorado World Birding Center	Harlingen	www.trails.com/tcatalog_trail.aspx?trailid=XFA059-045
Las Estrellas Preserve	Protecting the population of the endangered *Astrophytum asterias* (star cactus)	The Nature Conservancy, Starr County	www.nature.org/ourinitiatives/region/northamerica/unitedstates/texas/index.htm
Lennox Foundation Southmost Preserve	Protecting remnant *Sabal mexicana* (sabal palm) forest along the lower Rio Grande	The Nature Conservancy, Brownsville	www.nature.org/ourinitiatives/region/northamerica/unitedstates/texas/index.htm
Los Palomas Wildlife Management Area: 18 tracts, including Prieta Unit, MacWhorter Unit, and Chapote Unit	Wildlife management, particularly habitat conservation for *Zenaida asiatica* (white-winged dove)	Weslaco	www.tpwd.state.tx.us

Table 11. Prominent annual festivals, activities, and locations related to wildlife and conservation in the four-county area of the Lower Rio Grande Valley in southern Texas.—Continued

[LRGV, Lower Rio Grande Valley; USFWS, U.S. Fish and Wildlife Service; NWR, national wildlife refuge]

Name	Purpose	Sponsor and (or) location	Related link (accessed April 2016)
Related to conservation—Continued			
McAllen Nature Center	Educational activities and family nature walks	McAllen	www.mcallen.net/parks-recreation/mcallen-nature-center
National Butterfly Center	Dedicated to education and conservation for butterflies in the LRGV	Mission	www.nationalbutterflycenter.org
Palo Alto Battlefield	Preservation of a Mexican-American War battlefield, providing access to undeveloped grassland bound by thickets of mesquite and cactus	Brownsville	www.nps.gov/paal/learn/historyculture/paloalto.htm
Rio Grande Valley Chapter of Texas Master Naturalist	Dedicated to volunteer education and outreach to enhance conservation of natural resources in the LRGV	San Benito	www.rgvctmn.org
Rio Grande Delta Audubon Society	Dedicated to conservation of bird diversity in the LRGV	Brownsville	www.riograndedeltaaudubonsociety.org
Sabal Palm Sanctuary	Protection of a rare community of sabal palms and associated wildlife along the Rio Grande, in cooperation with the Gorgas Science Foundation	Brownsville	www.sabalpalmsanctuary.org and www.gsfinc.org
Texas State Parks Bensten-Rio Grande Boca Chica	Recreation and conservation of unique habitats in the LRGV	Mission and Brownsville (vicinity), respectively	www.tpwd.texas.gov
Valley Proud Environmental Council	Sponsor of Rio Restoration for past 24 years, enhancing native habitats of the LRGV	Harlingen	www.valleyproud.org
Valley Land Fund	Expanding and enhancing native wildlife habitat in the LRGV	McAllen	www.valleylandfund.com
World Birding Centers Bentsen-Rio Grande Valley Edinburg Scenic Wetlands Estero Llano Grande Harlingen Arroyo Colorado Old Hidalgo Pumphouse Quinta Mazatlan Resaca de la Palma Roma Bluffs South Padre Island and Nature Center	Highlighting the rich bird communities of the LRGV, focusing on education	Mission at Bentsen-Rio Grande State Park; nine centers providing access to a great variety of habitats and wildlife from Roma to South Padre Island in the LRGV	www.theworldbirdingcenter.com

Adjacent to the latter two State parks, the TPWD manages the Mercedes and Noriega tracts of the Lower Rio Grande Valley NWR.

The Nature Conservancy owns three conservation preserves in the LRGV, but management is limited because of border security issues. Close to the Sabal Palm Sanctuary, the Nature Conservancy's Lennox Foundation Southmost Preserve protects 414 ha (1,023 acre) of sabal palm forest, in which rare plants and animals are protected. The Nature Conservancy also has been active in Starr County (and a few places in Mexico) by purchasing land and acquiring conservation easements to protect the endangered star cactus. The 168-ha (415-acre) Las Estrellas Preserve protects the star cactus and associated species. In Hidalgo County, the Nature Conservancy's 142-ha (350-acre) Chihuahua Woods Preserve protects a community of cacti, unlike anywhere else in the LRGV, and it might transfer ownership of the preserve to the Lower Rio Grande Valley NWR. The Nature Conservancy actively partners with other public and private concerns in the LRGV, using habitat restoration, landowner outreach, and biotic inventories to further conservation goals.

The National Audubon Society has several active chapters in the LRGV that promote conservation of birds and their habitats. The National Audubon Society protected the 225-ha (557-acre) Sabal Palm Sanctuary, one of the largest remaining groves of sabal palms in Texas, but after completion of the border fence that affected the sanctuary, the National Audubon Society turned over management and oversight of the site to Gorgas Science Foundation which operates a gift shop and streams a live video camera of birds at a feeder in the sanctuary, with support from the Rio Grande Valley Chapter of Texas Master Naturalist.

The Friends of the Wildlife Corridor is a nonprofit organization that was founded in the LRGV in 1997. Its primary functions are to protect and restore native habitat in the last 322 km (200 mi) of the lower Rio Grande. The Friends of the Wildlife Corridor purchase and temporarily hold land until the USFWS can purchase it from them (these purchases are typically small acreages but can serve very important roles in connecting existing NWR land); operate the gift store at Santa Ana NWR (profits from sales of educational, interpretive, and promotional materials support NWR projects); support the volunteer program, construction of trails and boardwalks, and purchases of outreach and educational materials; secure grants to help build, for example, the overlook tower at Santa Ana NWR; conduct outreach through special events, a Web site, brochures, and other promotional materials; and finally, lobby at local and national levels for land acquisition funding and other issues that affect wildlife conservation in the LRGV. The Friends of Laguna Atascosa NWR provide similar services (table 11), often with a focus on the largest population of northern ocelots that occurs there.

The Valley Land Fund owns the Salineño tract, adjacent to the Kepler tract of the Lower Rio Grande Valley NWR; a management agreement allows the USFWS to manage the Valley Land Fund's property. This site is a top birding destination in the LRGV where three oriole species are regularly visible and where the rare *Psilorhinus morio* (brown jay) and red-billed pigeon can be sighted on a fairly reliable basis. The Valley Proud Environmental Council has cosponsored the annual Rio Reforestation event for the past 24 years. Rio Reforestation is the USFWS annual opportunity to engage the public, primarily middle and high school students, with planting former farmland back to native vegetation, often in the flood plain areas of the LRGV. Supporting Rio Reforestation and other restoration activities in the LRGV, American Forests of Washington, DC, has provided nearly $1 million over the past 10 years to leverage the reforestation programs of the Lower Rio Grande Valley NWR. Funds received from donations are transferred to the Lower Rio Grande Valley NWR to purchase seedlings. The Conservation Fund of Arlington, Virginia, has played a large role in land acquisition, particularly in Laguna Atascosa NWR.

Cooperation with Mexico

Personnel from USFWS Ecological Services-Corpus Christi and STRC have worked with agencies in Mexico to enhance conservation in the LRGV borderlands since at least 1994. In 2001, the Lower Rio Grande/Rio Bravo Binational Ecosystem Group was established with representatives from USFWS, TPWD, the Nature Conservancy, the Mexican State of Tamaulipas, Comisión Nacional de Áreas Naturales Protegidas (CONANP, Mexican equivalent to the USFWS), and Pronatura Noroeste México (major Mexican conservation NGO). This group produced a binational ecosystem management plan that addressed pernicious habitat impacts on both sides of the international border and common specific concerns about natural resources and wildlife conservation.

In 2005, the Lower Rio Grande/Rio Bravo Binational Ecosystem Group added eight partners from Mexico, and a Memorandum of Understanding (MOU) was signed by the USFWS, TPWD, and Mexican agencies including wildlife- and conservation-related agencies from Tamaulipas and Nuevo Leon, Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, CONANP, and Pronatura Noroeste México. A major goal of the MOU was to establish international habitat corridors linking the protected area of Sierra Picachos in Nuevo León, Mexico, with similarly protected areas in Tamaulipas, Mexico, and along the lower Rio Grande in Mexico, eventually connecting with tracts in the Lower Rio Grande Valley NWR in the United States. The group has sponsored international symposia over the years to share information and highlight acquisition and restoration efforts to establish international habitat corridors. These efforts have been challenged since the border fence was completed.

A connected international wildlife corridor along the Rio Grande could benefit a variety of species of migratory and resident birds, bats, mammals, and butterflies. To be successful, such a corridor will require restoration, conservation easements and land acquisition, and research on flora and fauna in the United States and Mexico. Northern ocelots, in particular, could benefit from a corridor that connects its small United States population to the larger populations in Tamaulipas, Mexico. One current binational effort by at least 12 United States and Mexican agencies, organizations, and universities is led by the Translocation Working Group, a subcommittee of the Ocelot Recovery Team that includes, among others, the Tamatán Zoo (Ciudad Victoria), Gladys Porter Zoo, Dallas Zoo, and Environmental Defense Fund, and is focused on introduction of northern ocelots from Tamaulipas, Mexico, into the United States population to bolster its low genetic diversity (Translocation Working Group, 2009). Until a functional wildlife corridor can be established between the United States and Mexican populations, this is the only option to augment low genetic diversity of northern ocelots in the United States and decrease their high probability of extirpation (Haines, Tewes, Laack, and others, 2006).

Conservation and Land Acquisition

The USFWS acquires land in the LRGV from willing sellers. Fee purchase, conservation easements, lease agreements, management agreements, donations, gifts, and administrative transfer or exchanges are used to acquire, manage, and protect land from habitat loss and ultimately conserve the land in perpetuity. For example, the Monte Cristo tract in the Lower Rio Grande Valley NWR was exchanged for the 3,006-ha (7,428-acre) Yturria easement in 2015 to enhance conservation of northern ocelots. Nevertheless, funding for land acquisition is complicated and depends on many factors, including Federal administrative and political interest. As mitigation for habitat loss from construction of the border fence, the USFWS anticipated $20 million from the U.S. Department of Homeland Security for land acquisition in the Rio Grande Valley Sector. Nearly $3 million was received by the end of 2014, with little assurance then that more would be forthcoming. The U.S. Department of Homeland Security must rely on the U.S. Army Corps of Engineers to purchase land to mitigate for impacts, and in early 2015, it was announced that the U.S. Department of Homeland Security could not commit to the full $20 million.

Originally, State and Federal agencies and NGOs agreed to establish a wildlife corridor adjacent to the Rio Grande in the United States from the Boca Chica tract on the Gulf Coast to Falcon Dam in Starr County to benefit endangered species and migratory birds. Since the border fence was completed in 2008, some conservation organizations and agencies in the LRGV have transferred their land and management activities to the Lower Rio Grande Valley NWR or private foundations. As a result, previous efforts to establish a wildlife corridor along the lower Rio Grande have been thwarted. Seven wildlife management areas and Boca Chica State Park owned by TPWD were transferred under long-term agreements in July 2007 to the Lower Rio Grande Valley NWR; most of the management areas are relatively small and close to the river, with no public access, fishing, or hunting opportunities that could generate income for Texas. The Nature Conservancy's Sabal Palm Sanctuary protects a vestige of a unique forest type in the LRGV, and its management was transferred to the Gorgas Science Foundation in 2009.

The STRC owns or manages lands and water rights within jurisdictional boundaries of 13 of 29 water-irrigation districts in the LRGV. Since its establishment in 1979, the Lower Rio Grande Valley NWR has maintained a beneficial management agreement with the Delta Lake Irrigation District. In June 1990, a cooperative agreement was established to protect and manage a strip of wildlife habitat associated with the Willacy Canal system along 44.2 km (27.5 mi) from the Santa Maria tract on the Rio Grande northward to Delta Lake and the area midway between the Rio Grande and the East Lake/La Sal Vieja tract—a stretch called the Otha Holland Canal/Wildlife Corridor (fig. 19). It represents the only corridor where wildlife can safely travel from the Rio Grande north of Interstate 2—the major east-west, 4–6-lane highway bisecting the entire LRGV; culverts enable safe passage of species such as northern ocelots beneath Interstate 2. In exchange for management and protection by the Lower Rio Grande Valley NWR, the Delta Lake Irrigation District agreed to allow native habitat on at least one bank of the canal to afford wildlife a vegetated corridor close to freshwater in which to travel. This agreement was renewed, with modification, in June 2015. The new agreement requires the Lower Rio Grande Valley NWR to contribute part of its annual water-rights allocation to the Delta Lake Irrigation District for preserving habitat along its 122-m-wide (400-foot-wide) canal easement, of which about 61 m (200 ft) is vegetation.

The new agreement between the Delta Lake Irrigation District and Lower Rio Grande Valley NWR is precedent setting and will permit the USFWS to leverage its water rights to irrigation districts, landowners, or other entities by providing them water in exchange for conservation benefits, primarily planting or allowing the vegetation to recover along their linear canal systems. These agreements could increase the extent of vegetated wildlife corridors to accommodate movements of terrestrial mammals between the broader LRGV and Laguna Atascosa NWR and among larger tracts in the Lower Rio Grande Valley NWR. The Lower Rio Grande Valley NWR has 2.71×10^7 cubic meters (22,000 acre-feet) of water rights. Expanding agreements similar to the agreement renegotiated with the Delta Lake Irrigation District could enhance conservation in the LRGV.

Currently, most water-irrigation districts, particularly those in Cameron County, regularly clear vegetation on both banks of their canals, which provides no habitat benefits and, in fact, is a detriment to most wildlife. Acquiring equipment that could help water-irrigation districts do necessary maintenance without having to clear all bankside vegetation might be an incentive to protect habitat for wildlife while continuing to effectively move water as needed. District canal systems typically hold water for all or part of the year. When these canals cross a major road or highway, they typically have culverts or provide opportunities for wildlife to pass safely beneath the road. Permitting terrestrial species to travel along canal networks is a viable way to protect essential wildlife habitat in the LRGV. Such habitat protection and restoration opportunities could provide a network of corridors throughout the LRGV, offering wildlife opportunities to move about in an otherwise largely cleared and fragmented agricultural and urbanized landscape.

Future Management Directions and Needs

Nearly 30 years ago, Jahrsdoerfer and Leslie (1988, p. 40) summarized the future "resource protection and management strategy" of the Lower Rio Grande Valley NWR with a five-step integrated approach to land conservation: (1) give "high priority in acquisition and preservation planning" to communities under particular threats; (2) acquire, repair, and maintain a riparian corridor along the Rio Grande; (3) maintain and acquire large anchor tracts (e.g., East Lake/La Sal Vieja, Falcon Woodland, and Boca Chica tracts) to conserve "biological material to safeguard gene pools and replenish wildlife populations throughout the corridor"; (4) strategically locate management units "to provide food, water, and cover for selected target populations"; and (5) conserve unique, intact islands of important wildlife value left untouched when the Rio Grande Delta was cleared. Under this integrated approach to land management and conservation in the LRGV, Jahrsdoerfer and Leslie (1988) provided 18 specific recommendations as templates for future directions. Perhaps the best measurement of progress since then is the fact that the Lower Rio Grande Valley NWR increased 320 percent in size from 50 tracts of about 9,817 ha (27,300 acres) in 1988 to 147 tracts of 39,035 ha (96,458.4 acres) in 2015. Although the Lower Rio Grande Valley NWR is less fragmented than it was in the late 1980s, it remains, in general, a series of small and often isolated tracts with limited connectivity, which leaves some tracts vulnerable to local extirpations and ecosystem degradation.

To help fulfill the overall mission of the USFWS refuge system and parallel its vision from the late 1980s (Jahrsdoerfer and Leslie, 1988), the main goal for habitat management in the Lower Rio Grande Valley NWR is to enhance, restore, and protect native communities unique to the LRGV. To meet needs of trust-resource species, the USFWS and its partners developed land protection plans in 1983 (USFWS, 1983), 1985 (USFWS, 1985), and 1999 when Laguna Atascosa NWR amended its plans for land acquisition (USFWS, 2010e). Since these plans were established, many State, Federal, and private partners have been constrained by multiple factors (e.g., increasing land prices, limited funding, and border fence issues) in their abilities to acquire properties in the LRGV. Nevertheless, the USFWS continues to focus, in part, on broad landscape-level partnerships to complete its strategic acquisitions, habitat protection, and habitat-restoration objectives. Five large landscape corridors in the LRGV and three international corridors between the United States and Mexico are now major foci of conservation efforts for STRC and its partners (fig. 23).

Strategic land-acquisition planning conducted by STRC takes into account many current and projected impacts (table 12) such as sea-level rise from climate change, transportation and wildlife-crossing needs, urban growth, border issues, physical barriers such as border security infrastructure, the border fence, and the floodway levee, balanced by the USFWS's mandatory requirements to protect trust-resource species of the United States. The endangered northern ocelot provides an example of the urgent need for additional conservation and actions to reach its recovery goals and those of other endangered plants and animals in the LRGV (e.g., tables 5 and 6). Without human intervention, the northern ocelot could become extirpated in the United States within 50 years (Haines, 2006: Haines, Tewes, Laack, and others, 2006). The two most important factors limiting recovery of the northern ocelot are lack of connection of remaining suitable habitat and vehicle mortality. Northern ocelots in Texas are found in two subpopulations with no known physical connections between them and larger remnant populations in Mexico. Achieving recovery goals for the northern ocelot in the United States requires strategic habitat planning that crosses international boundaries (Translocation Working Group, 2009; USFWS, 2010a).

As described in the 2001 USFWS Policy on Biological Integrity, Diversity, and Environmental Health (USFWS, 2001), the goal of habitat management on NWRs is to ensure long-term maintenance and, where appropriate, restoration of ecosystems while considering management's contribution at various landscape scales. Because of the extreme diversity of species and habitats within the LRGV, the approach to acquisition and management of habitats by STRC considers current and historic conditions of an area and constraints on present-day management of these resources.

Resources of concern in the Lower Rio Grande Valley NWR, and therefore the entire STRC, and activities associated with their conservation encompass international, national, regional, and local conservation goals; State fish and wildlife conservation plans; recovery plans for threatened and endangered species; and habitat needs of migratory birds. These concerns are outlined in approved refuge resource-management plans (e.g., USFWS, 1983, 1985, 1997, 2010e), most recently following the 2000 USFWS Policy on the Comprehensive Conservation Planning Process (USFWS, 2000). Management and conservation of resources by the STRC support purposes and missions of the USFWS refuge system and conserve biological integrity, diversity, and environmental health of the LRGV, giving special consideration to rare, declining, or unique natural communities and species.

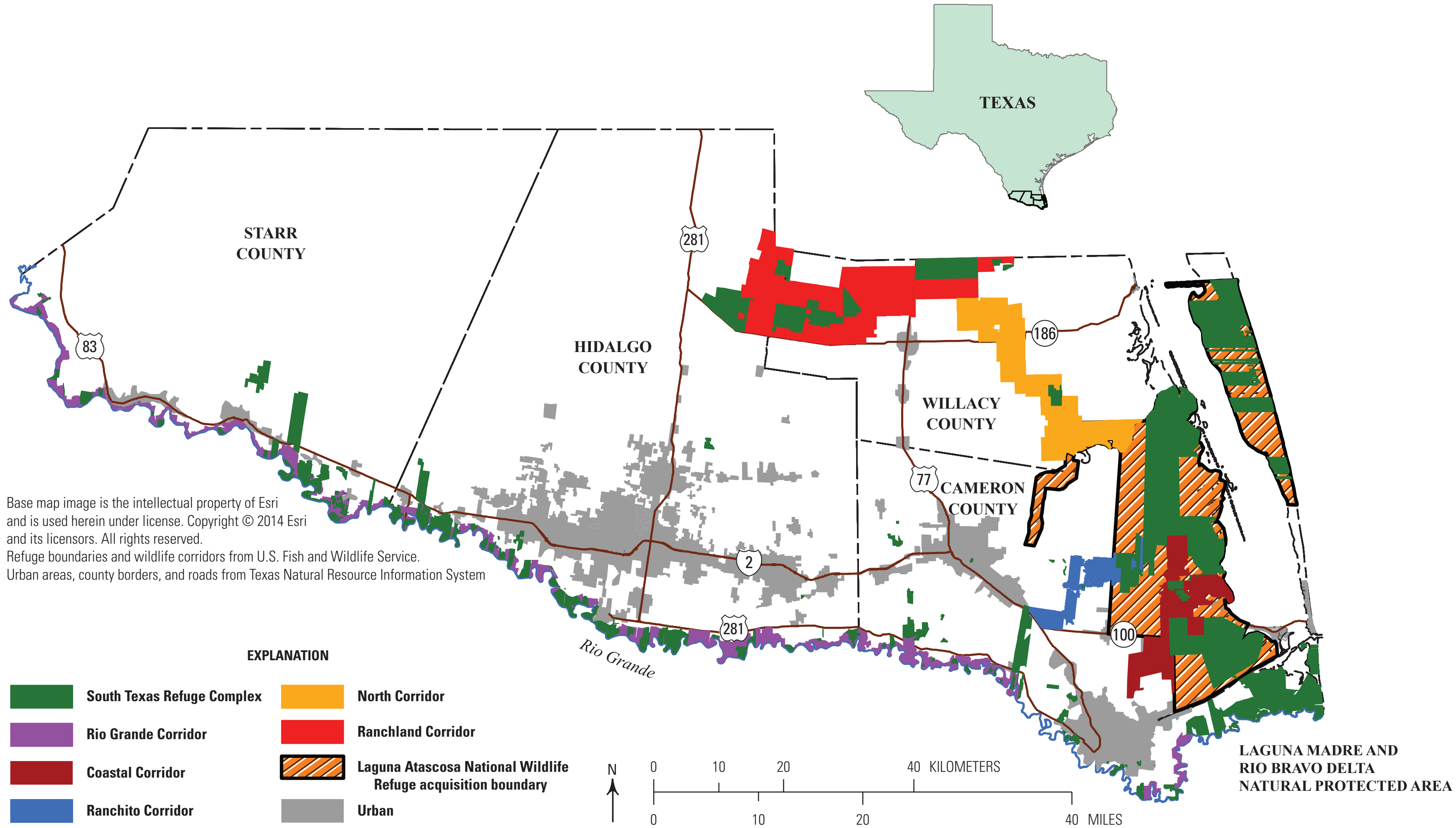


Figure 23. Planned wildlife corridors to connect critical tracts and habitats in the United States and Mexico, including the future acquisition boundary approved for the Laguna Atascosa National Wildlife Refuge.

Table 12. Present-day conservation and management challenges facing the Lower Rio Grande Valley and management concerns and options, generally ranked from most to least challenging or severe.

[LRGV, Lower Rio Grande Valley; LNG, liquefied natural gas; FERC, Federal Energy Regulatory Authority; NWR, national wildlife refuge; USFWS, U.S. Fish and Wildlife Service; kg, kilogram; ha, hectare; km, kilometer; STRC, South Texas Refuge Complex; cm, centimeter; ROW, right of way; %, percent; m, meter; <, less than]

Challenges	Key impacts and metrics	Management concerns and options
Land acquisition	• Conflicts with rezoning in response to expanding urbanization and conservation objectives throughout the LRGV (likely most problematic in Cameron County). • Land values and speculation in the LRGV among the highest in Texas (for example, $2,900 per acre for farm and [or] ranch land vs. an average of $1,196 per acre in Texas in 2007).	• Adequate funding (for example, from the Land and Water Conservation Fund) and help from nonprofit partners are the most important conservation tools. • Acquisition of key lands necessary to establish corridors and connections of sufficient in size to protect LRGV diversity for the long term; emphasis needed to complete the North Corridor. • Maintain an active role in local urban planning to protect key corridors and critical wildlife habitats.
Energy development	• At least 15 wind farms companies, with 1,373 turbines and 132 planned or proposed as of May 2015 (see table 8). • LNG facilities proposed along Brownsville Ship Channel near Port Isabel; three facilities had "prefiling" applications with the FERC as of April 2015. • Risk of shale development in the Eagle Ford Shale Region.	• Port development and coastal wind farms could negatively impact the Coastal Corridor between Boca Chica and Bahia Grande (tracts in the Lower Rio Grande Valley NWR), and Laguna Atascosa NWR. • USFWS needs to be aware of the FERC process for LNG facilities and maintain its role in proposal reviews and mitigation outcomes (if any). • Oceanic contamination could increase if LNG development occurs along the Brownsville Shipping Channel. • Lower Rio Grande Valley Development Council, part of the Council of Government Alliance, to explore shale oil development; USFWS could develop a working relationship with the Council.
Industrial development	• Space X, a private launch facility for rockets (payloads about 4,500 kg [9,920 pounds]) adjacent to the 8,903-ha (22,000-acre) Boca Chica tract. • Proposed STARGATE facility associated with Space X near Boca Chica tract, a public-private association between the University of Texas Brownsville's Center for Advanced Radio Astronomy and Space X. • Continued growth of the industrial border zone.	• Space X launches will require periodic closure of public land within a 5-km (3-mile) radius of launch site. • If Space X buys private inholdings in the 5-km radius, it could improve connectivity of Boca Chica with non-USFWS land and enhance conservation activities. • Monitoring effects of industrial growth on STRC properties, particularly along the Rio Grande. • Maquiladoras (Mexican factories) constantly expanding near international bridges.
Border issues	• 18 of 21 segments of the LRGV border fence (91 km [57 miles]) completed by 2008. • Number of border-patrol agents increased from 418 in 1988 to 3,064 in late 2014. • In 2014, the number of apprehensions of Mexicans illegally entering the United States fell to a low of 229,178 after peaking at 1,600,000 in 2000.	• USFWS to work cooperatively with border patrol to minimize impacts of growing disturbance (for example, increased vehicle, boat, helicopter, and horse patrols). • More patrol disturbance means less illegal human traffic on tracts of the Lower Rio Grande Valley NWR, but ongoing disturbance needs to be minimized.

Table 12. Present-day conservation and management challenges facing the Lower Rio Grande Valley and management concerns and options, generally ranked from most to least challenging or severe.—Continued

[LRGV, Lower Rio Grande Valley; LNG, liquefied natural gas; FERC, Federal Energy Regulatory Authority; NWR, national wildlife refuge; USFWS, U.S. Fish and Wildlife Service; kg, kilogram; ha, hectare; km, kilometer; STRC, South Texas Refuge Complex; cm, centimeter; ROW, right of way; %, percent; m, meter; <, less than]

Challenges	Key impacts and metrics	Management concerns and options
Human population growth	• Increase in United States human population in the LRGV from about 400,000 in 1960s to 1,317,156 in 2013, perhaps reaching 3 million by 2050. • Similar increase in Mexico; for example, 633,730 people in Reynosa and 462,157 in Matamoros in 2013. • Increased tourism to the LRGV and South Padre Island, with proposal to build a second causeway near the south end of Laguna Atascosa NWR.	• Little can be done to curb population growth, but careful and vigorous zoning and restrictions to protect open spaces can enhance conservation outcomes and improve human health. • Added pressure to convert agricultural land, with some value to wildlife, to urbanized areas. • Increased danger from Cartel activity in Mexico, causing Mexican citizens to legally move to the United States LRGV. • Need for expanded transportation infrastructure throughout LRGV fragments habitat and increases wildlife-vehicle collisions—major cause of death for *Leopardus pardalis albescens* (northern ocelot). • Plans to complete STRC's Coastal Corridor compromised by proposed second causeway to South Padre Island.
Invasive species	• At least 20 invasive plant species in the LRGV (see table 10). • Two major exotic large mammal species (*Boselaphus tragocamelus* [nilgai] and *Sus scrofa* [feral pig]).	• Native species outcompeted by invasive species, altering native habitats. • Major flooding in 2010 facilitated spread of disturbance-adapted *Tamarix ramosissima* (saltcedar) in the lower Rio Grande, which can displace riparian tree species, greatly modifying the Rio Grande Wildlife Corridor. • Invasive grasses often develop monocultures in upland areas, greatly increasing risk of fast-moving and fine-fuel fires. • Exotic nilgai are controlled by the U.S. Department of Agriculture to minimize transmission of tick-borne diseases to cattle.
Climate change	• Gulf Coast of the United States has experienced greater sea-level rises over the past 100 years (20.3–101.6 cm [8–40 inches]) than global averages (10.2–20.3 cm [4–8 inches]). • Projected relative sea-level rises by the year 2100 are 0.2–0.61 m (0.66–2 feet) at Port Mansfield and 0.34–0.75 m (1.1–2.5 feet) at South Padre Island. • Temperatures will continue to rise, with more severe droughts and more erratic fluctuations.	• Elimination or modification of coastal habitat for migratory shorebirds and marine turtle nesting from sea-level rise. • Laguna Madre could become too deep for tidal flats and seagrasses. • Erratic climate cycles, related to temperature and precipitation, could be normal, hampering restoration efforts in the Lower Rio Grande Valley NWR.

Table 12. Present-day conservation and management challenges facing the Lower Rio Grande Valley and management concerns and options, generally ranked from most to least challenging or severe.—Continued

[LRGV, Lower Rio Grande Valley; LNG, liquefied natural gas; FERC, Federal Energy Regulatory Authority; NWR, national wildlife refuge; USFWS, U.S. Fish and Wildlife Service; kg, kilogram; ha, hectare; km, kilometer; STRC, South Texas Refuge Complex; cm, centimeter; ROW, right of way; %, percent; m, meter; <, less than]

Challenges	Key impacts and metrics	Management concerns and options
Habitat restoration	• Habitat fragmentation a threat from human development pressure (more and wider roads, more and larger utility infrastructure, etc.). • Restoration is a key to habitat management in the LRGV; for example, more than 3 million seedlings were planted in the Lower Rio Grande Valley NWR from 1995 to 2011. • Land purchases by USFWS more complicated now because of increasing land value and speculation with expanding urbanization (see above).	• Need to develop a strategy for ecological restoration of tracts in the Lower Rio Grande Valley NWR. • Retired farmlands do not revert to lush diverse forest because land clearing in the LRGV was so widespread and years of agriculture so intense that little to no seed bank is left and soils tend to be salty. • Ability to reforest former agricultural land near the Rio Grande hampered by limited availability of native seedlings of the 45–60 species needed. • Lack of or limited availability of commercially produced native seeds for ROW plantings for use by other agencies and (or) land owners. • Nonnative grasses or annual grasses still used for ROW (pipelines, roads, etc.) plantings, further impacting diversity of native species.
Water availability	• Water will eventually be limited in the LRGV, but sufficient water rights for STRC's needs are currently available. • Farms and ranches in Cameron and Hidalgo Counties decreased by 35,622 ha (88,025 acres) from 1997 to 2007—most loss to urbanization. • Irrigated crops still important demand on water but irrigated land in Cameron and Hidalgo Counties decreased 16% from 1997 to 2007—most loss to urbanization.	• Lower Rio Grande Valley NWR has 2,713.7 hectare-meters (22,000 acre-feet) of Class B water rights for annual use. • 13 cooperative farmers use Lower Rio Grande Valley NWR tracts; only five have access to water for irrigation. • Cooperative farmers not allowed to plant crops that require a lot of water (for example, cotton or sugarcane).
Pesticides, contamination, and pollution	• 98 pesticides commonly used in the LRGV in 1998; today, at least 23 of those banned and 8 others under restricted use by the U.S. Environmental Protection Agency. • In 2008, six landfills with an average of 12 more years of use handled 410,000 tons per year from the LRGV. • Air quality in the LRGV is affected by vehicle exhaust, industrial/power plant emissions, and seasonal burning of mostly sugarcane.	• Fast-growing human population in the LRGV results in higher demand for landfills (with a shortage of places to put them), recycling centers, and other depositories for human wastes. • Increased risk of environmental contamination as demands increase for pipelines to move gas and (or) oil from wells west of and through the LRGV. • Intensive use of pesticides and other chemicals are not allowed by USFWS because of their effects on biological resources.

Wildlife Corridors

Wildlife corridors of native habitats connecting nearby and even isolated tracts in the STRC have been consistently identified as important assets in need of expansion, connection, and restoration (fig. 23); for example, in the comprehensive conservation plans for Lower Rio Grande Valley NWR and Santa Ana NWR (USFWS, 1997) and for Laguna Atascosa NWR (USFWS, 2010e). These corridors are critically important for reestablishment of habitats used by trust resources in the LRGV and beyond. Acquisition, protection, and restoration of optimal and even currently suboptimal habitats are critical in management of migratory birds and recovery of numerous rare, threatened, or endangered species in southern Texas. Given significant changes in the landscape of southern Texas since earlier conservation plans were written, including but not limited to exponential population growth and urban expansion, land-acquisition authorities of the STRC's three NWRs may not be enough to provide habitat resources needed to support trust resource responsibilities indefinitely; thus, an alternate expansion-planning document (land protection plan) is being prepared to support STRC's strategic habitat planning.

The USFWS uses a variety of information to assess where strategic acquisition of additional land would be the most useful and logistically possible to enhance wildlife corridors (e.g., interpretation of aerial imagery, existing and predicted barriers to wildlife dispersal, and models of sea-level rise predicted from climate change). Five corridors for strategic acquisition have been identified as critical areas to support wildlife conservation in the LRGV: Rio Grande Corridor, Ranchito Corridor, Coastal Corridor, North Corridor, and Ranchland Corridor (fig. 23). From its creation in 1979, the Lower Rio Grande Valley NWR has been familiarly called the "Wildlife Corridor," reflecting the still-apt priority to conserve an east-west linear corridor along the Rio Grande from the Gulf inland to benefit the unique riparian plant communities and animal species, such as the endangered northern ocelot.

The USFWS has also worked with agencies in Mexico to establish three international wildlife corridors that are anchored to State- and federally protected natural areas in northern Mexico and Federal properties in southern Texas, (i.e., Sierra Picachos-Rio Grande International Wildlife Corridor, Rio Grande Corridor [in this case, on both sides or either side of the Rio Grande from the Boca Chica tract on the Gulf to Falcon Reservoir in the western LRGV], and United States-Mexico Coastal Corridor). The Canada/Mexico/U.S. Trilateral Committee for Wildlife and Ecosystem Conservation and Management has endorsed these international corridors.

The Rio Grande Corridor serves as a major artery for the long-term sustainability of the diverse ecosystems in the LRGV (fig. 23) and, in fact, motivated the creation of the Lower Rio Grande Valley NWR in 1979 (Jahrsdeorfer and Leslie, 1988). Protecting riparian habitats along the Rio Grande and in coastal areas could provide buffers against climate change. Riparian habitats along the Rio Grande provide habitat for some of the most rare migratory bird species or species with the most restricted distributions in the United States (table 6). The Rio Grande Corridor could permit dispersal of northern ocelots between conservation areas in Mexico and the United States, as demonstrated by the female that moved from Mexico to Santa Ana NWR and raised two offspring in 1992–96 (B.R. Winton, oral commun.). Genetic analyses showed that the female was genetically more similar to northern ocelots in Mexico than those in Cameron or Willacy Counties (Walker, 1997). She presumably had a mate nearby, but he was never documented. Another male was found near the Rio Grande east of Brownsville, Tex., in 1998 that travelled >30 km (>18 mi) to Laguna Atascosa NWR. The full development of the Rio Grande Corridor could also protect essential habitat for several endangered or rare plants (table 5).

The Coastal Corridor will complete the United States contribution of the binational corridor to connect the northern ocelot population in Laguna Atascosa NWR to the population in Tamaulipas, Mexico, through the Natural Protected Area in the Lower Laguna Madre area in the United States and the Delta del Rio Bravo in Mexico, separated by the Rio Grande Delta (fig. 23). Acquisition of land to complete the Coastal Corridor could protect some of the highest priority areas that have had recent use by northern ocelots. It could provide an opportunity for dispersal of northern ocelots between Laguna Atascosa NWR and Mexico through natural dispersal events. The Ranchito Corridor could provide an alternative route for northern ocelots from the Coastal Corridor to disperse to other protected areas along the Rio Grande Corridor and along existing, but perhaps tenuously protected, corridors in northern Mexico (fig. 23). The area has abundant wetlands, including many resacas. Major routes within the Ranchito Corridor could protect habitat from some of the modeled predictions of sea-level rise (Intergovernmental Panel on Climate Change, 2007, 2014). If sea-level rise is worse than predicted in southern Texas (e.g., Schmandt and others, 2011), inland movement of terrestrial species such as the northern ocelot and the Gulf Coast jaguarundi could be possible through the Ranchito Corridor, where disturbed habitats are very restorable.

The North Corridor is also essential to the long-term conservation of northern ocelots because it could reconnect the two known populations of northern ocelots in the United States, one of which was recently documented on private lands and tracts of the Lower Rio Grande Valley NWR (fig. 23). These areas contain patches of dense but isolated brush and many patches of savannah, open brushlands, and coastal grasslands that provide usable habitat for the northern aplomado falcon and perhaps transitory and foraging habitat for the northern ocelot. The Nature Conservancy, USFWS, and TPWD plan to reestablish brushlands on these lands. Some of the successional brushlands of this area were cleared periodically to maintain grazing land and habitat for game species. Favorable soils allow quick reestablishment of brushlands through natural processes, and northern ocelots use these areas to forage at night. Restoring parts of these areas to dense brushlands could provide more core-area habitat of northern ocelots and the Gulf Coast jaguarundi but still contain adjacent grasslands as productive foraging areas for northern aplomado falcons.

The Ranchland Corridor is in the recently discovered range of northern ocelots around the saline lake area of the LRGV, and conservation in this area could connect northern ocelots and other terrestrial species with the North Corridor (fig. 23). The North Corridor connects Laguna Atascosa NWR northward to the Lower Rio Grande Valley NWR conservation easements, where northern ocelots reside, and onto the La Sal Vieja area where a future crossing on U.S. Highway 77 will be constructed to facilitate safe wildlife movements. The North Corridor will expand westward to the protected area adjacent to the northern ocelot population in Willacy County and is critical for increasing long-term survival and recovery of the northern ocelot in the United States. The Ranchland Corridor has much in common with the North Corridor and is critical to the recovery of the northern ocelot and northern aplomado falcon because it provides similar brushy and grassy habitats. Continuing to connect and expand these corridors with new land acquisition could greatly enhance recovery of endangered species and a multitude of other unique flora and fauna in the LRGV.

Staff of the STRC frequently evaluates and modifies, if needed, its preferred strategy to spend future funds on land acquisition. These evaluations take into account those lands already under STRC management, connectivity opportunities to complete corridors including the Rio Grande Corridor, ongoing development pressures such as Space X, proposed liquefied natural gas facilities near Port Isabel, new and expanding wind farms, a second access causeway to South Padre Island, associated land-value speculation, and impacts the border fence will have on any future efforts (table 12). Infrastructure associated with some of these activities probably affects north-south movements of terrestrial wildlife near the Rio Grande. Where the border fence and associated border-patrol activities are sufficiently north of the Rio Grande, vegetated areas remain along the river itself. Therefore, in such areas, it seems most useful and efficient to acquire properties that remain available adjacent to the Rio Grande and existing tracts of the Lower Rio Grande NWR. This effort could further the ability of the STRC to provide a contiguous stretch of habitat that will allow restoration and preservation of riparian forests. Concurrently, the STRC could divest itself of tracts with low biodiversity value that are isolated from adjacent tracts or are surrounded by urbanization with no reasonable expectation that the USFWS will acquire additional lands within the area. Examples include the Goodfields tract and certain tracts in the Brownsville, Tex., metropolitan area (e.g., Jeronimo Banco, Champion Bend, and Villa Nueva) that are significantly degraded or where they no longer serve a corridor function. These tracts could be exchanged for tracts that better meet conservation goals of the STRC, unless they could be used for public education and involvement.

Conclusion

As this synthesis of mostly LRGV-centric peer-reviewed literature since the late 1980s attests, the LRGV is one of the most biologically unique areas in the entire United States, with much of the flora and fauna found nowhere else north of Mexico. Scientists have long been attracted to the LRGV to study its varied abiotic and biotic characteristics on land and in fresh, estuarine, and marine waters. Very few, if any, four-county areas in the United States have been the site of such varied scientific investigation and resulting publications (table 1). The LRGV also draws ecotourists from across the country and abroad, who come to experience subtropical to semiarid wildlands and wildlife-watching opportunities that can be found only in the four southernmost counties of Texas. Visitors support many local businesses, contributing significant capital into an otherwise impoverished region.

It is relatively straightforward to list, and even rank, the conservation challenges in the LRGV (table 12), but for many challenges, it is very difficult to predict outcomes precisely and likely more a matter of dealing with them as they present themselves—some slowly and insidiously, others quickly and more obviously. Climate change can only be measured over a long term, but loss of wildlands to urbanization and resulting fragmentation can be assessed quickly. Climate change challenges our approach to conservation of biodiversity, and it is becoming clear that integration of disciplines (e.g., social science, urban planning, and ecology) is required and that planning must extend “beyond reserves and into human-occupied landscapes” (Heller and Zavaleta, 2009, p. 14). Precise prediction of how climate change will affect a particular area and its ecosystems is still very difficult, but “identifying primary local climate drivers,” climate sensitivities, and risk tolerances of ecosystems/communities with conservation concern is easier to accomplish (Snover and others, 2013, p. 1147). In the LRGV, for example, the conservation value of existing tracts of protected land in the STRC might be compromised if species shift to areas not in the STRC (Carroll and others, 2010; Monzón and others, 2011), so expanding property and corridors could be useful conservation objectives.

In many conservation plans, fragmentation and lack of connectivity of important wild landscapes are understood to be negative impacts, but only 30 percent of States in the United States have specific criteria and (or) plans to identify and link important wildlife areas (Lacher and Wilkerson, 2013). In sharp contrast, the USFWS at the STRC has a clear plan to establish five wildlife corridors with viable connections of key protected habitats in the United States and Mexico. Well-defined goals of corridors need to be expressed in the context of six ecological functions that can be very species specific; a corridor can represent a conduit, a habitat, a filter, a barrier, a source, and (or) a sink, or a combination depending on its dimensions, location, and habitat quality (Hess and Fischer, 2001). A recent meta-analysis of 35 studies demonstrated that movement of organisms increased about 50 percent between habitats connected by corridors; movements were more evident for plants, invertebrates, and nonbird vertebrates than for bird species (Gilbert-Norton and others, 2010). Nevertheless, monitoring of newly established corridors could be needed because even well-defined and well-intentioned corridors could cause negative effects, such the spread of invasive species (e.g., fire ants—Resasco and others, 2014) or decrease nest success of particular birds susceptible to nest predation (Weldon, 2006). Generally, however, wide corridors with edges that meld into the surrounding vegetation matrix tend to minimize these problems (Haddad and others, 2014).

Overall, LRGV-centric research published since Jahrsdoerfer and Leslie (1988) was driven by a few species (e.g., ocelots) or topics (e.g., seagrasses and agricultural pests), and it generally lacked interdisciplinary outlooks (e.g., how human activities and impacts impinge on conservation needs and success, table 1). Some collected references in this report (e.g., appendixes *A*–*C*) could be used by managers of the STRC and other State and Federal agencies with responsibilities for, or activities than impinge on, natural resources in the LRGV to direct future research in areas of priority and deficiency. Currently, there is little interagency prioritization of integrated research needs and collective direction reflected in the published research reviewed herein, and as a result, each agency typically proceeds by itself, with research foci only on its mission. Correcting this deficiency could bring research focus to areas of mutual concern and need, particularly with regard to conservation in the LRGV.

A rapidly increasing human population in the LRGV will be the major conservation challenge for many years to come. As the population in the LRGV rises in the coming decades, threats to conservation that we see now (table 12) will only become more severe. As more people make the LRGV their home, resources such as water and land will become increasingly difficult to obtain. Land prices have already risen sharply in the LRGV since the 1990s, and as such, government land-acquisition guidelines now limit the ability of the STRC to acquire additional land. As the human population and land prices in the LRGV increase, it will become more difficult for the STRC to acquire land. Because of increased conservation threats and the likelihood of continually increasing land prices in the LRGV, this could be the last and best time to purchase land to complete the wildlife corridors associated with the Lower Rio Grande Valley NWR, Laguna Atascosa NWR, and international interests.

The LRGV obviously has great biological richness, but it now faces great conservation challenges from a century or more of use and modification by increasing numbers of humans, leaving behind aquatic and terrestrial "novel ecosystems" (Hobbs and others, 2006, p. 1; Marris, 2009). These ecosystems "arise either from the degradation and invasion of 'wild' or natural/seminatural systems or from the abandonment of intensively managed systems" (Hobbs and others, 2006, p. 2). Marris (2009, p. 450) referred to the resulting matrix of natural, managed, and urbanized areas as our "ragamuffin Earth." Because such matrices dominate so many areas around the world, particularly those juxtaposed with rapidly growing or already large human populations, as is the case in the LRGV, a growing number of ecologists and restoration specialists are calling for theoretical and practical ways to consider "novel ecosystems" valuable, to various degrees, for conservation efforts; this is in part because of great cost and difficulties in completely restoring such areas to some notion of what they were in the past (Hobbs and others, 2006)—a challenge that restoration efforts in the LRGV have faced. Along with conservation agencies such as the USFWS, urban ecologists and planners have growing responsibilities to help maintain and restore biodiversity and the ecosystem services it provides (e.g., Marzluff and Ewing, 2001; McKinney, 2002; Hobbs and others, 2006, 2011; Pickett and others, 2013; Palomo and others, 2014).

Conservation challenges facing the LRGV are among the most difficult in the United States. Continued careful syntheses of existing and future information collected in the LRGV are needed on many biological and sociological topics to avoid spending precious time and resources rediscovering something that it is already widely known and accepted. Quick response would be beneficial to address contemporary ongoing challenges such as climate change, water availability, energy and industrial development, spread of invasive species, and habitat loss and fragmentation caused by urbanization. Rapidly growing human populations compete with extensive agricultural lands for increasingly rare resources in an already compromised natural landscape in the LRGV. Complexities of a guarded international borderland add pressure to the small patches of native habitat that remain along the lower Rio Grande. Large connected corridors of restored native habitat could perhaps be the best chance of maintaining, and even enhancing, the exceptional biodiversity in the LRGV in the face of exceptional human demand.

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Appendixes

Appendix A. Research conducted on seagrass of the Lower and Upper Laguna Madre since the early 1990s.

Main topical emphasis	Laguna Madre	
	Lower	Upper
Algal "brown tide"	Onuf (2000)	Dunton (1990, 1996); Montagna and others (1993); Whitledge (1993); Onuf (1996a); Buskey and others (1997, 2001); Street and others (1997); Rhudy and others (1999); Ward and others (2000)
Elemental metabolism	Opsahl and Benner (1993); Ziegler (1998); Ziegler and Benner (1998); Lee (1998); Lee and Dunton (1999a, 1999b); Major and Dunton (2000)	Koepfler and others (1993)
Productivity and biomass/recovery	Dunton and Tomasko (1994); Herzka (1996); Herzka and Dunton (1997, 1998); Kaldy (1997); Hicks and others (1998); Kaldy and others (1999, 2002); Kowalski (1999); Kaldy and Dunton (2000); Lee and Dunton (2000); Ziegler and Benner (2000); Kowalski and others (2009)	Dunton (1994); Czerny and Dunton (1995); Tomasko and Dunton (1995); Burd and Dunton (2001); Gutierrez and others (2010)
Changing interspecific seagrass community dynamics	Onuf (1996b, 2007); Kaldy and Dunton (1999)	Onuf (1996c, 2007)
Damage (dredging, propeller, etc.) and restoration	Quammen and Onuf (1993); Onuf (1994); Kaldy and others (2004)	Dunton and Schonberg (2002); Martin and others (2008); Larkin and others (2009)
Number of papers (by seagrass species)	27	21
Halodule wrightii (shoal grass)	6	7
Thalassia testudinum (turtle grass)	11	0
Syringodium filiforme (manatee grass)	1	0
Ruppia maritima (widgeongrass)	0	1
In general or mixed-species research	9	13

Appendix B. Peer-reviewed publications focused on the Lower Rio Grande Valley (referred to as "LRGV centric") (not including books, book chapters, and theses but including some relative monographs in the "Birds of North America" series) on 58 bird species since the late 1980s.

Species	Number of peer-reviewed papers	References[a]
Amazilia yucatanensis (buff-bellied hummingbird)	1	Chavez-Ramirez and Moreno-Valdez (1999)
Amazona viridigenalis (red-crowned parrot)	1	Enkerlin-Hoeflich and Hogan (1997)
Ammodramus maritimus (seaside sparrow)	1	Phillips and Einem (2003)[b]
Ardea herodias (great blue heron)	1	Mora (1995)
Arremonops rufivirgatus (olive sparrow)	2	Wright (1996); Brush (1998b)
Calidris mauri (western sandpiper)	1	White and Mitchell (1990)
Camptostoma imberbe (northern beardless-tyrannulet)	3	Brush (1999a)[b]; Werner (2004); Werner and others (2015)
Cardinalis sinuatus (pyrrhuloxia)	1	Patrikeev (2006)
Charadrius melodus (piping plover)	5	Drake (1996a, 1996b); Garza (1997); Drake and others (2001); Mehl and others (2003)
Charadrius nivosus (snowy plover)	2	Rupert (1997b); Mehl and others (2003)
Coccyzus americanus (yellow-billed cuckoo)	1	Clotfelter and Brush (1995)
Cyanocitta cristata (blue jay)	1	Brush (2000b)[b]
Cyanocorax yncas (green jay)	3	Clotfelter and Brush (1995); Gayou (1986, 1995)
Egretta rufescens (reddish egret)	1	Huysman (1995)
Egretta thula (snowy egret)	1	Mora (1995)
Egretta tricolor (tricolored heron)	1	Mora (1995)
Falco femoralis septentrionalis (northern aplomado falcon)	11	Perez (1995); Perez and others (1996); Mora and others (1997, 2008, 2011); Keddy-Hector (2000); Brown and others (2003, 2006); Jenny and others (2004); Brown and Callopy (2008, 2012)
Falco peregrinus (peregrine falcon)	3	Chavez-Ramirez and others (1994); Enderson and others (1995); Henny and others (1996)
Geothlypis poliocephala (gray-crowned yellowthroat)	1	Lorenz and others (2006)[b]
Glaucidium brasilianum (ferruginous pygmy-owl)	3	Wauer and others (1993); Proudfoot and others (1999); Proudfoot and Johnson (2000)
Hydroprogne caspia (Caspian tern)	1	Mora (1995)
Icterus cucullatus (hooded oriole)	1	Brush (2000c)
Icterus graduacauda audubonii (Audubon's oriole)	4	Brush (2000d); Flood and others (2002); Monk (2003); Monk and Brush (2007)
Icterus gularis (Altamira oriole)	5	Brush (1998c); Hathcock and Brush (2004); Werner (2004); Brush and Pleasants (2005); Werner and others (2007)
Leptotila verreauxi (white-tipped dove)	6	Boydstun and DeYoung (1985, 1987, 1988); Hayslette (1996); Hogan (1999); Hayslette and others (2000)
Limnodromus scolopaceus (long-billed dowitcher)	1	White and Mitchell (1990)
Megaceryle torquata (ringed kingfisher)	1	Brush (2009b)

Appendix B. Peer-reviewed publications focused on the Lower Rio Grande Valley (referred to as “LRGV centric”) (not including books, book chapters, and theses but including some relative monographs in the “Birds of North America” series) on 58 bird species since the late 1980s.—Continued

Species	Number of peer-reviewed papers	References[a]
Micrathene whitneyi (elf owl)	2	Gamel (1997); Gamel and Brush (2001)
Molothrus aeneus (bronzed cowbird)	7	Clotfelter and Brush (1995); Brush (2000c); Hathcock (2000); Warren (2002); Kostecke and others (2004); Monk and Brush (2007); Gorton (2010); Janecka and Brush (2014)
Ortalis vetula (plain chachalaca)	1	Peterson (2000)
Pachyramphus aglaiae (rose-throated becard)	2	Brush (2000a)[b]; Miller and others (2015)
Parula pitiayumi (tropical parula)	2	Regelski and Moldenhauer (1997); Brush (1999a)[b]
Patagioenas flavirostris (red-billed pigeon)	3	Brush (1998a); Lowther (2002); Breeden and others (2009)
Pelecanus erythrorhynchos (American white pelican)	1	Chapman (1988)
Petrochelidon fulva (cave swallow)	3	Musquiz (2003); Mora and others (2005, 2006)
Petrochelidon pyrrhonota (cliff swallow)	3	Musquiz (2003); Mora and others (2005, 2006)
Pitangus sulphuratus (great kiskadee)	3	Brush (1993); Gorena (1995); Brush and Fitzpatrick (2002)
Plegadis chihi (white-faced ibis)	1	Custer and Mitchell (1989)
Quiscalus mexicanus (great-tailed grackle)	3	Glahn and others (1997); Johnson and others (1989); Wehtje (2003)
Recurvirostra americana (American avocet)	1	White and Mitchell (1990)
Rynchops niger (black skimmer)	2	Custer and Mitchell (1987); King and others (1991)
Sayornis nigricans (black phoebe)	1	Brush (2001)[b]
Spiza americana (dickcissel)	1	Larkin and others (2002)
Sterna forsteri (Forster’s tern)	1	King and others (1991)
Tiaris olivaceus (yellow-faced grassquit)	1	Brush (2003)[b]
Tringa semipalmata (willet)	1	Custer and Mitchell (1991)
Turdus grayi (clay-colored robin)	1	Brush (2000a)[b]
Tyrannus couchii (Couch’s kingbird)	2	Clotfelter and Brush (1995); Brush (1999b)
Tyrannus verticalis (western kingbird)	1	Clotfelter and Brush (1995)
Waterfowl		
Anas acuta (northern pintail)	1	Ballard and others (2004)
Anas clypeata (northern shoveler)	2	Tietje and Teer (1996); Tietje and Vreeland (1997)
Aythya americana (redhead)	11	Mitchell (1991, 1992); Moore (1991); Mitchell and others (1992, 1994); Woodin (1994, 1996); Custer and others (1997); Skoruppa and Woodin (1997); Woodin and others (2008); Ballard and others (2010)
Cairina moschata (Muscovy duck)	1	Brush and Eitniear (2002)
Dendrocygna autumnalis (black-bellied whistling duck)	2	Fedynich and others (1996); Edmonds and Stolley (2008)

Appendix B. Peer-reviewed publications focused on the Lower Rio Grande Valley (referred to as "LRGV centric") (not including books, book chapters, and theses but including some relative monographs in the "Birds of North America" series) on 58 bird species since the late 1980s.—Continued

Species	Number of peer-reviewed papers	References[a]
Diving ducks (general)	1	Adair (1990)
Mergus serrator (red-breasted merganser)	1	Rupert and Brush (1996)[b]
Nomonyx dominicus (masked duck)	2	Anderson and Tacha (1999); Eitniear (1999)
Zenaida asiatica (white-winged dove)	11	Swanson and Rappole (1992); Tacha and others (1994); Schacht and others (1995); Hayslette (1996); Hayslette and others (1996, 2000); Small and Waggerman (1999); Sepúlveda and others (2006); Fredericks and others (2009); Collins and others (2010); Ruiz (2012)
Zenaida macroura (mourning dove)	4	Hayslette (1996); Hayslette and others (2000); Collins and others (2010); Ruiz (2012)
Nonspecies specific		
Community	16	Gehlbach (1987); Bauer (1993); Muehl (1994); Brush (1995, 2008a, 2008b); Adair and others (1996); Balin (1996); Cantu (1996); Castillo (1997); Rupert (1997a); Brush and Cantu (1998); Fernandez (1999); Gallegos (2001); Rupert and Brush (2006); Rappole and others (2007)
Contaminants (waterbirds)	6	Mora (1996a, 1996b); Corson and others (1998); Wainwright (1998); Wainwright and others (2001); Maruya and others (2005)
Range expansion	1	Brush (2009a)
Total	**166**	

[a]White and Mitchell (1990) involved American avocet, long-billed dowitcher, and western sandpiper; King and others (1991) involved black skimmer and Forster's tern; Mora (1995) involved Caspian tern, great blue heron, snowy egret, and tricolored herons; Brush (1999a) involved northern beardless-tyrannulet and tropical parula; Brush (2000a) involved clay-colored robin and red-throated becard; Brush (2000c) involved bronzed cowbird and hooded oriole; Hayslette (1996) and Hayslette and others (2000) involved mourning dove, white-tipped dove, and white-winged dove; Mehl and others (2003) involved piping plover and snowy plover; Musquiz (2003) and Mora and others (2005, 2006) involved cave swallow and cliff swallow; Monk and Brush (2007) involved Audubon's oriole and bronzed cowbird; and Collins and others (2010) involved white-winged dove and mourning dove. These 12 publications were double-counted.

[b]New nesting records for the LRGV.

Appendix C. Peer-reviewed publications focused on the Lower Rio Grande Valley (referred to as "LRGV centric") (not including popular publications or graduate theses) on northern ocelots by subject categories since the late 1980s.

Subject	Number by subject[a]	References[b]
Conservation		
General and habitat improvement	10	Tewes (1986); Tewes and Everett (1986); Laack (1991); Young (1992); Young and Tewes (1994); Haines, Caso, and others (2005); Haines, Tewes, Laack, and others (2005); Haines (2006); Haines, Janečka, and others (2006); Grigione and others (2009)
Corridors	3	Tewes and others (1995); Tewes and Hughes (2001); Nordlof (2015)
Highway/bridges/artificial lights	4	Fischer (1998); Hewitt and others (1998); Tewes and Blanton (1998); Grigione and Mrykalo (2004)
Contaminants	1	Mora and others (2000)
Demography		
Population viability	3	Haines, Tewes, Laack, and others (2006); Haines and others (2007); Sternberg and Mays (2011)
Reproduction	1	Laack and others (2005)
Survival	1	Haines, Tewes, and Laack (2005)
Diseases and parasites	3	Mercer and others (1988); Pence and others (1995, 2003)
Drought	1	Tewes and Hornocker (2008)
Field techniques		
Hair snares	1	Weaver and others (2005)
Immobilization	2	Beltrán and Tewes (1995); Shindle and Tewes (2000)
Telemetry (Global Positioning System)	1	Haines, Grassman, and others (2006)
General	7	Navarro-Lopez (1985); Tewes and Everett (1986); Tewes and Miller (1987); Tewes and Schmidly (1987); Brown (1990); Navarro-Lopez and others (1993); Murray and Gardner (1997)
Genetics and phylogenetics	7	Walker (1997); Janečka (2006); Janečka, Grassman, and others (2006, 2007); Janečka, Walker, and others (2007); Janečka and others (2008, 2011)
Habitat use and assessment	12	Shindle (1995); Harveson (1996); Anderson and others (1997); Fischer (1998); Shindle and Tewes (1998); Tewes and others (1999); Jackson (2002); Shinn (2002); Harveson and others (2004); Haines, Caso, and others (2005); Jackson and others (2005); Connolly (2009)
Interspecific (bobcats)	4	Horne (1998); Horne and others (2009); Booth-Binczik and others (2013); Nordlof (2015)
Total	**61**	

[a]References can appear in more than one category depending on content.

[b]A few references published in or just prior to 1988 were not included in Jahrsdoerfer and Leslie (1988) but are included here.

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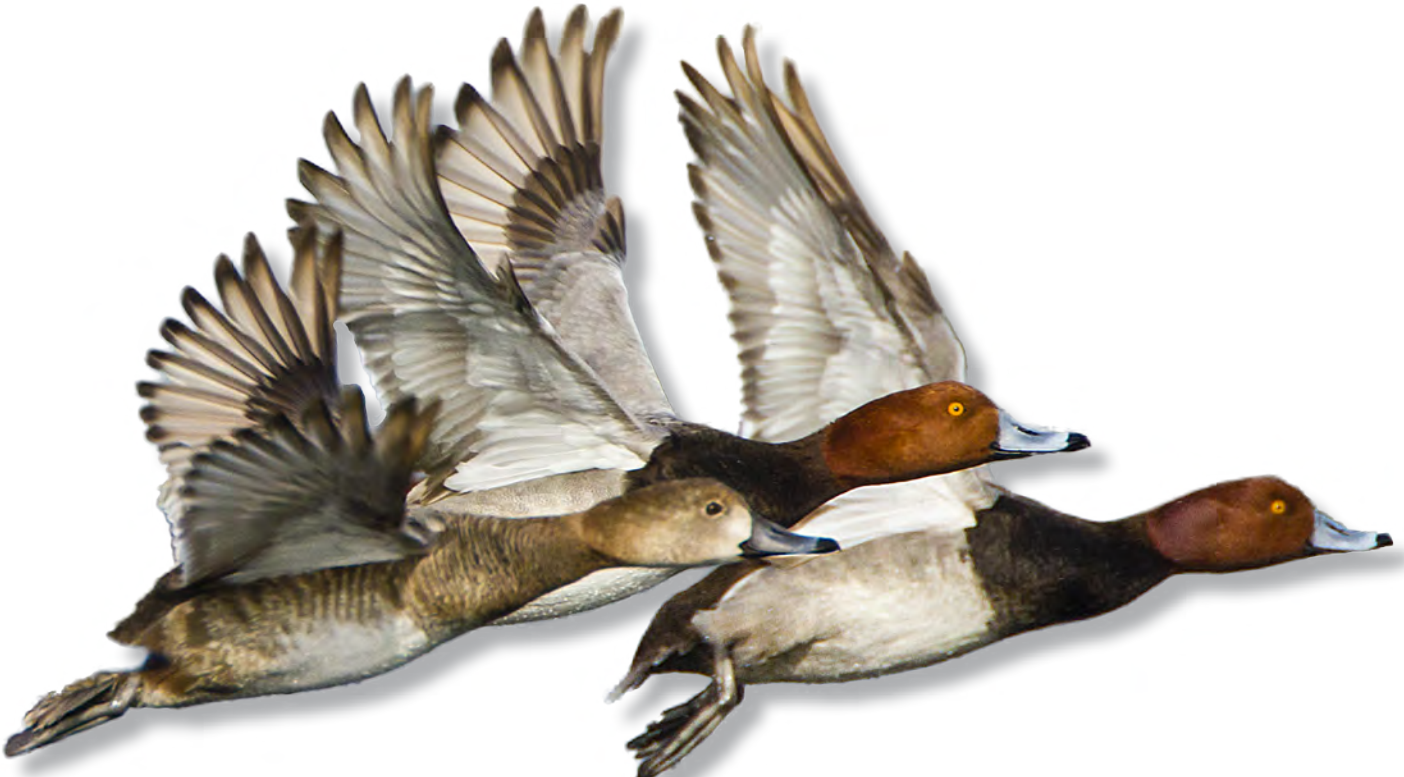

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