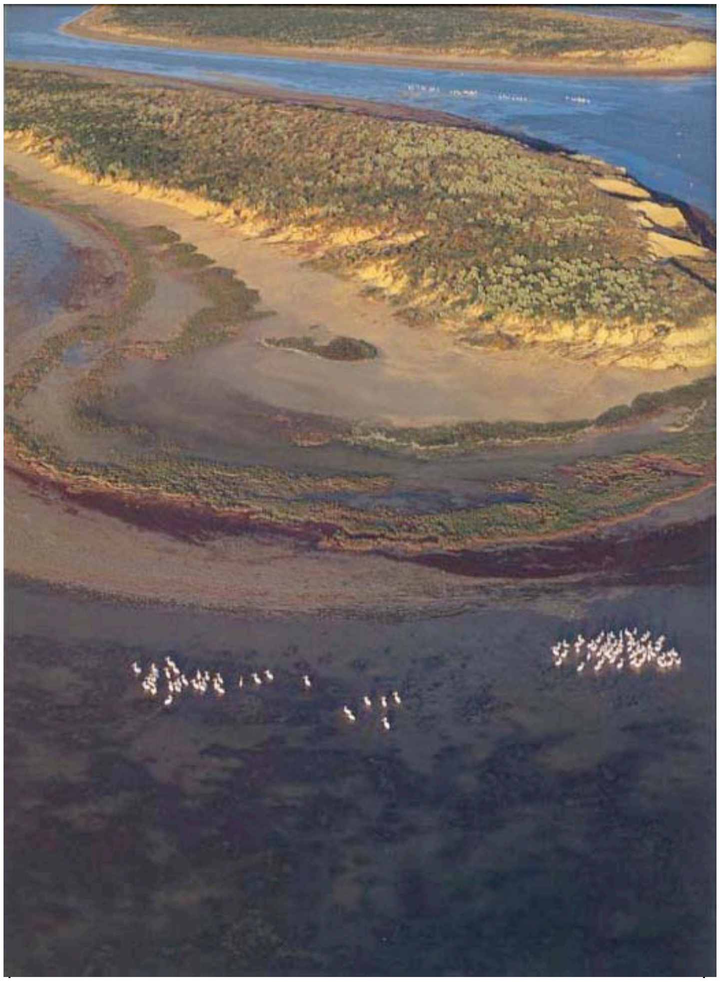
BACKGROUND PAPER 2011-02

Aquatic Invasive Species

in the Río Bravo / Laguna Madre Ecological Region



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Cover:
Aerial view of the Laguna Madre estuary,
a unique hypersaline ecosystem, and
the most important wetland in North America.
Photo: Patricio Robles Gil

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Executive Summary

This report was commissioned to review and assess existing data on biological invasions (or potential future impacts, where available) in the Rio Bravo/Laguna Madre Ecological Region. This effort forms part of an overall strategy to contribute to the protection and management of key ecosystems in North America (Priority Conservation Regions, or PCRs) from the potentially harmful effects of invasive species. The impact on biodiversity and ecological integrity from invasive species is second only to outright habitat destruction or modification.

Laguna Madre of Texas and Tamaulipas is the only coastal, hypersaline lagoon system on the North American continent and is recognized as the largest of the seven known hypersaline ecosystems of the world. The Laguna Madre is a Unesco Biosphere Reserve and RAMSAR site. Specifically, this region contains a diverse variety of sub-tropical and coastal ecosystems, including mangroves, dunes, and wetlands that provide habitat to many species including endemic turtles and shore birds. Moreover, this area is critical as a natural corridor for migratory waterbirds.

Methods of analysis for this report include an extensive search through peer reviewed sources of information (e.g., NAS-USGS, Conabio, Conanp, GSMFC-GSARP-AIS, ISSG, etc.), official Management Plans, and other specialized sources for information on invasive species within the Rio Bravo/Laguna Madre Ecological Region. Geographically, this includes the states of Louisiana and Texas, in the US, and, in Mexico, the state of Tamaulipas. All species reported were compiled in a database and categorized in six major groups; plants, invertebrates, fishes, amphibians and reptiles, mammals, and others (virus, bacteria, protozoan and fungus). Once this list was integrated, a fact sheet for each species was prepared with the necessary information to perform subsequent pathway analysis.

Findings indicate that there are 373 exotic species (100 plants, 85 invertebrates, 162 fishes, 10 amphibians, 4 reptiles 1 mammal, 1 fungus, 2 protozoa, 4 bacteria and 4 viruses) present or reported in neighboring states of the Rio Bravo/Laguna Madre Ecological Region, of which 94 are scored as having critical impact. Out of those, 94 focal species, 6 are currently found only in Mexico, 65 occur only in the United States and only 2 are potential invasive species reported in neighboring states to the region. Furthermore, 28 of the 100 most invasive species listed by IUCN are found within the region. A more detailed assessment of each species can be found in the fact sheets.

In addition, the report draws attention to the fact that most of the exotic species are transplants from the Atlantic costal region, and have been introduced largely by sport fishing, aquaculture, ballast water discharges, aquarium trade, use as bait and the effects of coastal transportation. However, the majority of the species identified originate from other continents, with the most important source region for exotic plants being Asia.

A common problem encountered when addressing invasive species is a lack of sufficient biological and ecological information to support the decision making process that might prevent or reduce impacts to biodiversity. This is where new methodological approaches such as those developed within the expanding domain of Biodiversity Informatics are showing promise, allowing the generation of new information from resources, knowledge products, and policy advice from disparate data sources.

The report recommends that in order to protect the native ecosystem of the Rio Bravo/Laguna Madre Ecological Region, it will be necessary to implement not only preventive actions, such as Hazard Analysis and critical control point (HACCP) and risk analysis, but also coordinated binational (US and Mexico) actions of control and eradication of those species determined as critical in this study.

Introduction

Ecologically, North America is a mosaic. The ecosystems of North America are diverse and highly productive, containing valuable natural resources and unique natural features of worldwide significance and great individuality. However, besides its ecological richness, North America also faces many environmental problems (CEC 1997). In most cases, environmental issues are complex and not restricted by jurisdictional boundaries but are shared among nations. In particular, the border region between the United States and Mexico encompasses a diverse array of physical habitats, which are unique in terms of the diversity of water, mineral, and biological resources. The region is interconnected economically, politically, and socially owing to its bi-national heritage. Unfortunately, the diverse and fragile ecosystems of the borderland have been pushed beyond sustainable levels by rapid population growth and land-use changes.

Environmental issues of particular concern include:

- contaminants in ground water, surface water, and biota from agricultural, municipal, mining, and industrial activities;
- airborne pollutants from fossil-fuel combustion and other activities;
- pathogens, pharmaceuticals, hormones, and other contaminants released in treated and untreated human and animal wastewaters (USGS 2004, 2007).

A major environmental problem that is just beginning to be considered at a bi-national level is the presence of invasive species[1] in shared ecosystems.

In fact, introduced species are considered a greater threat to native biodiversity than pollution, harvest, and disease combined (Simberloff 2000). Invasive exotic species are the second leading cause of biodiversity decline worldwide after habitat destruction (Krasny 2003), and thousands of non-indigenous species have been introduced in Mexico and the US as a result of intentional or unintentional human activities. Non-indigenous

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[1] The US National Invasive Species Management Plan (NISMP) defines an *invasive species* as "a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health." (ISAC 2006).

organisms are generally defined as any species or viable biological material (e.g., spores from microorganisms, seeds and fragments of plants, etc.) that enters an ecosystem beyond its historic range, including any organisms transferred from one country into another. Sometimes these non-indigenous organisms become invasive, causing harm to the environment, the economy or to human health. Harmful invasive plants and animals have already caused billions of dollars of damage to natural environments, business and consumers in both countries (Pimentel et al. 2005; Aguirre and Mendoza 2009). Non-indigenous species may be introduced through numerous pathways of dispersal (e.g., aquaculture, aquarium trade, ballast water discharges, fish stocking, etc.).

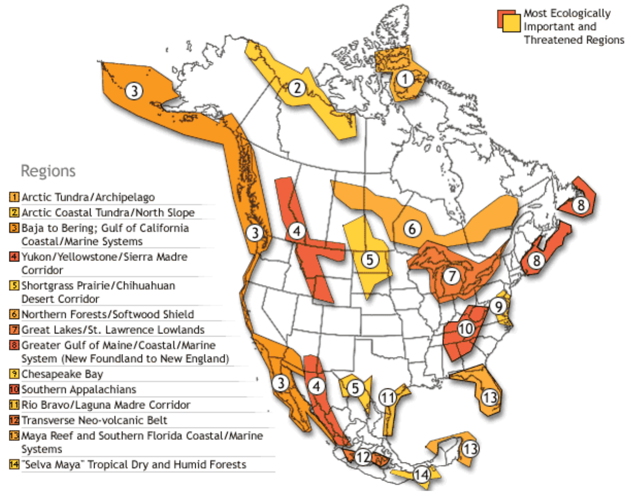
Natural communities, the ecological services they provide, and the sustainable use of living natural resources are at risk, and North Americans are seeking new means to protect the richness of life on our continent. It is important to recognize that the loss of biodiversity generally has a cascading or rippling effect on species, ecosystems, and economies, first felt locally, then nationally, and then regionally (CEC 2003a). Therefore, it is very important to develop a database that compiles the impacts and threats posed by aquatic invasive species in the region.

The present study fits into one of the specific goals of the CEC's Strategic Plan for North American Cooperation in the Conservation of Biodiversity: "Promote collaborative responses to threats facing North American ecosystems, habitats and species," and focuses specifically on analysis for the identification of extant aquatic invasive species and their pathways. The information resulting from this project will hopefully contribute to solving the problems posed by invasive species by applying common strategies in the region and thus, to preventing future invasions and the resulting damage to ecosystems and national economies.

Background of the Study

Within the CEC's Strategic Plan for North American Cooperation in the Conservation of Biodiversity a key stage was the identification of important regions for biodiversity conservation. For this purpose, in 2000, the CEC organized a workshop in which 14 regions of prime importance for focused North American attention were identified, based on biological and ecological continental significance and high levels of threat.

Figure 1. CEC: North America's 14 Most Ecologically Important and Threatened Regions



In a previous effort, The Nature Concerancy (TNC) was engaged with the CEC in developing criteria and systems to evaluate threats from invasive species to the CEC's 14 priority conservation regions (PCRs) (Burgiel and March 2008). On 18 June 2009, a meeting was held, involving different government agencies and members of the Mexican invasive species advisory group in order to select a region that Mexico could forward to the Biodiversity and Conservation Working Group (BCWG) members. When the criteria from the TNC report were reviewed and scored, the region that emerged as the top candidate for action was the Rio Bravo-Laguna Madre corridor (Region 11).

Importance of Region 11

In the CEC's 14 priority conservation regions the Rio Bravo-Laguna Madre corridor (Region 11) does not refer to the Laguna Madre exclusively but to an ecoregion corridor, the Laguna Madre and Rio Bravo delta corridor, that includes terrestrial and freshwater environments.

A very large number of reference works are available for the region (more than 1,300 according to Tunell and The Transboundary Resource Inventory Project). From these, a select number of articles and books[2] were consulted in the course of compiling the following summary.

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[2] Gunter 1967; Hildebrand 1969; Conner et al. 1989; TWDB and TPWD 1992; Conabio 2000; The Nature Concervancy of Texas 2001; Tunnell and Judd 2001; Pronatura-UAT-Conanp 2002; Tunell et al. 2002; Evaluación Alianza para el Campo 2006; Barraza & Calnan 2006; Onuf 2007; Pronatura Noreste 2009, and TNC-Pronatura-Conanp 2009.

Figure 2. Map of Ecoregion 11

The layers were provided by the CEC.

The Laguna Madre of Texas and Tamaulipas is the only coastal, hypersaline lagoon system on the North American continent and the largest in the world. Extending along 455 km (277 mi) of shoreline in south Texas and northeastern Mexico, the Laguna Madre is separated into two bodies of water by 75 km (47 mi) of the Rio Grande Delta. Each lagoon is about 185 km (115 mi) in length and is further divided into subunits; the upper and lower Laguna Madre in Texas are separated by the Land-Cut tidal flats, and the northern and southern Laguna Madre de Tamaulipas are separated by the El Carrizal tidal flats. Both lagoon systems are protected on the east by barrier islands and peninsulas, and bound on the mainland side by vast cattle ranches, farmlands, and the brush country of the Tamaulipan Biotic Province.

The Laguna itself is only eight kilometers (five miles) across at its widest point, with an average depth of less than one meter (three feet). As a consequence of the rapid evaporation of the shallow Laguna, the resulting hypersaline conditions create a premier nursery area for finfish, shrimp and shellfish.

The Laguna Madre is a complex mosaic of habitats, including shallow open waters and bays, lagoons, sea grass beds, mud and tidal flats, coastal barrier dunes, islands, seasonally flooded grasslands, mangroves, thornscrub, mesquite woodland and salt tolerant communities, dominated by Gulf cordgrass.

The Laguna Madre is the perfect example of a shared resource (Fig. 3). It is an ecosystem unit and is readily identifiable by all stakeholders on both sides of the border as a source of economic and ecologic wealth for the region (Barraza and Calnan 2006). Moreover, the relevance of the Río

Bravo/Laguna Madre Ecoregion relies on the links between priority conservation areas (national protected areas, marine and terrestrial GAP sites, critical habitats) and biological corridors.

Figure 3. Laguna Madre Satellite Image

Source: SNIB-Conabio, 2009.

This vast landscape of estuaries, beaches, shallow bays, salt marshes, grasslands, thorn scrub forests, oak mottes, and native palm groves that together form the Laguna Madre region is one of the most biologically diverse and visually stunning of America's natural treasures—a special place, a region with a huge variety of natural resources, some abundant, others rare and fragile (The Nature Conservancy of Texas 2001).

Extending along 277 miles of shoreline in south Texas and northeastern Mexico, the lagoon is renowned for its vast seagrass meadows, huge wintering bird population, and bountiful fishing grounds.

From the biodiversity standpoint the Río Bravo/Laguna Madre Ecoregion stands out from other areas because:

- It is the largest of the seven known hypersaline ecosystems in the world, with important intertidal swamplands and marshlands of some 50,800 hectares and vast, rich wetlands (DOF 2005).
- The Laguna Madre is a Biosphere reserve of the UNESCO's Man and the Biosphere (MAB) Network.[3] Specifically, this region has a high variety of tropical and coastal forests, including mangroves. In the

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[3] The Unesco Man and Biosphere Reserve Programme (MAB) was established in 1977 to promote an interdisciplinary approach to research, training, and communications in ecosystem conservation and the rational use of natural resources. Biosphere reserves are local protected areas that are intended to preserve a balanced and sustainable relationship between man and nature. The World Network of Biosphere Reserves is a listing of these local biosphere reserves, found in different countries, across all the regions of the world.

mosaic of different ecosystems, there are also dunes and wetlands that provide habitat to many species, including endemic turtles and beach birds. The importance of this area as a natural biogeographical corridor and a possible transition area can be seen when the high percentage (59%) of migratory waterbirds in the existing records of the area's bird diversity is compared to the percentage of resident species (38%). Also, the intertidal zones and the beaches serve as a very important habitat for coastal birds. The area is located in the Gulf's migration route, the most important in the continent for birds of prey. Two ecological management plans are already being carried out in the area to mitigate the stress caused by human impact on natural resources[4] (UNESCO 2009).

- The region was designed Ramsar[5] site No. 1362 (Fig. 4), (Ramsar 2009).
- The region forms part of the territory considered by the North American Wetlands Conservation Act[6] (Conanp 2006).
- Part of the region is considered a Priority Hydrological Region[7] (Fig. 5).
- The region is considered a Priority Marine Region in Mexico (Fig. 6).

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[4] Pronatura Noreste, A.C. Comisión Nacional de Áreas Naturales Protegidas and The Nature Conservancy, 2008. Plan de Conservación para La Laguna Madre y su Área de Influencia, Tamaulipas, México. The Nature Conservancy, NOAA, Texas Coastal Management Program. 2001. Conservation Plan for the Texas Portion of the Laguna Madre.

[5] The Convention on Wetlands of International Importance, called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

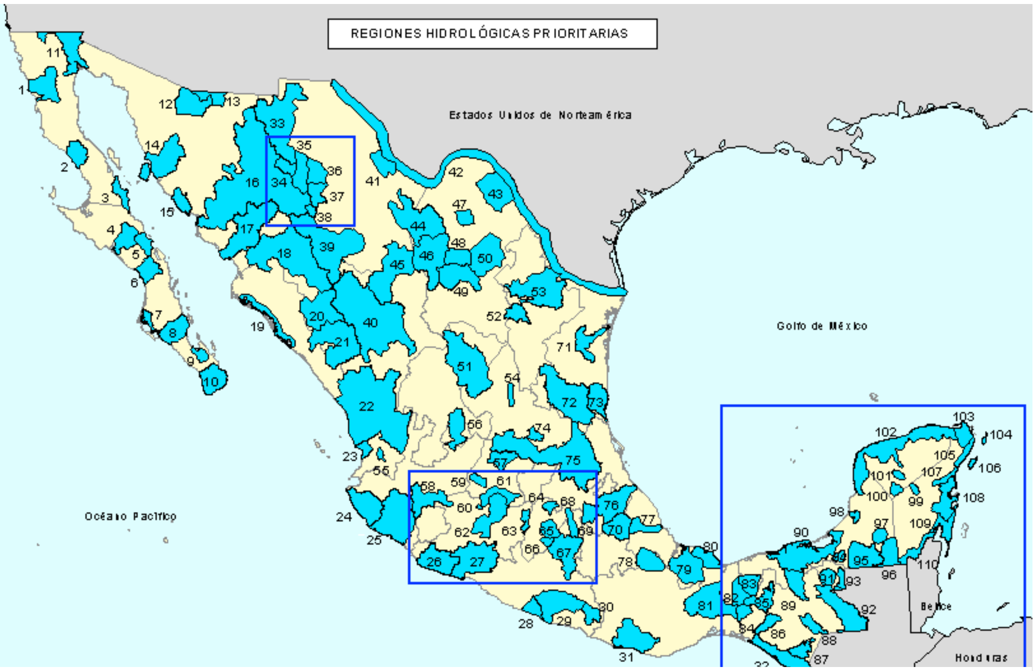
[6] The Act was passed to support activities under the North American Waterfowl Management Plan, an international agreement that provides a strategy for the long-term protection of wetlands and associated uplands habitats needed by waterfowl and other migratory birds in North America. At the present, its scope has been expanded to include the conservation of all habitats and birds associated with wetlands ecosystems.

[7] Priority Conservation Regions for Biodiversity in Mexico were identified by experts from universities, research institutes, and government and private institutions as well as NGOs (e.g., Conabio, Conanp, FMCN, Pronatura, Cipamex, CEC, David and Lucile Packard Foundation, WWF, USAID, TNC, BirdLife International, etc.).

Figure 4. RAMSAR sites in Mexico

Source: Conanp, 2009.

Figure 5. Priority Hydrological Regions in Mexico



Source: Arriaga Cabrera *et al.,* 2009.

Figure 6. Priority Marine Regions in Mexico

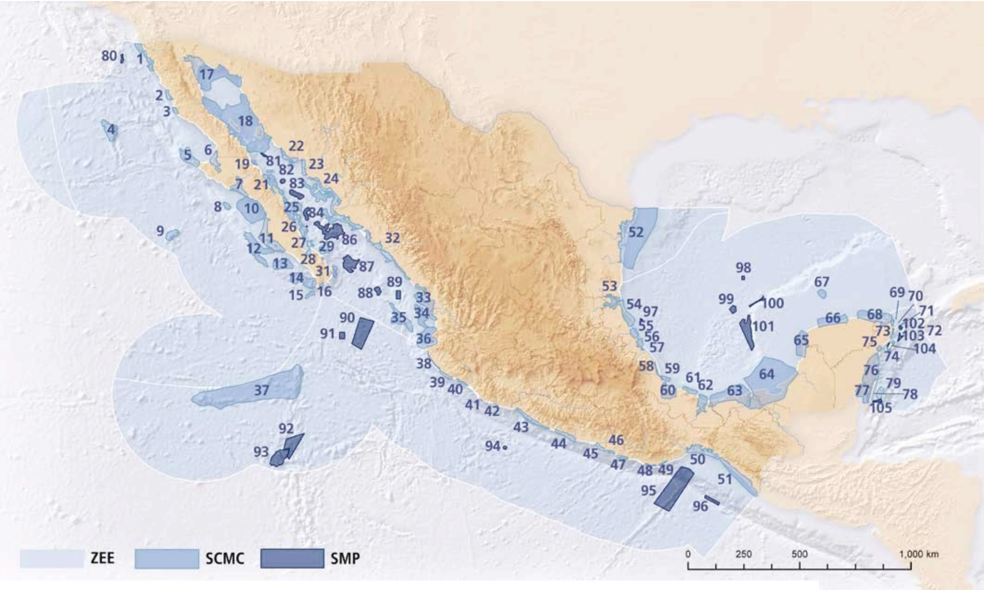
Source: Arriaga Cabrera *et al*., 2009.

- The region is a coastal and continental margin priority site for biodiversity conservation in Mexico (Fig. 7).
- The high biodiversity of the region of the Laguna Madre of Tamaulipas is due to its location between two of the world's major biogeographical zones running through Mexico: the Nearctical (North American) and Neotropical (Central and South American) realms. Two important hydrological regions drain into this zone, the Río Bravo basin and the San Fernando-Soto La Marina basin, and it has hydrological influences from two maritime regions, the Carolinean and the Caribbean, which are subject to different kinds of climates, pluvial regimes, and humidity, and constitute the northern limit for tropical vegetation such as mangroves and tropical forests (DFO 2005).
- Four species of mangroves are found in this region: red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*) and the button mangrove (*Conocarpus erectus*), which are protected species according to the Mexican Official Norm NOM-059-Semarnat-2001. These mangrove environments function as predation refuges for different species of economically valuable crustacean and fish larvae and as nesting sites for several species of birds (DOF 2005).
- It has been considered that the primary productivity of flooded areas is similar to that of seagrasses, allowing the development of benthic invertebrate communities that transform primary productivity into

animal biomass, essential for secondary consumers, such as crabs, fish and birds (DOF 2005).

- The endangered Atlantic Ridley or Kemp's Ridley Sea Turtle (*Lepidochelys kempii*) arrives and spawns in the region. In this case, invasive species are of particular concern, since they may harm sea turtle eggs or newborn turtles.
- *Gambusia affinis* and *Notropis jemezanus* are two endangered fish species inhabiting the region (Carrera 2004). These species may be displaced or subject to predation by introduced exotic fish.
- The region has also important areas of endemic terrestrial vegetation such as the Tamaulipas thornscrub, with records of endemic ebony (*Phitecellobium ebano*) (DOF 2005). Desert scrub of mesquite (*Prosopis glandulosa*), Blackbrush (*Acacia rigidula*), and Texan goatbush (*Castela tortuosa*), among others, is the most representative terrestrial vegetative species (Ramsar 2009).

Figure 7. Coastal, Continental Margin and Deepsea Priority Sites for Biodiversity Conservation in Mexico

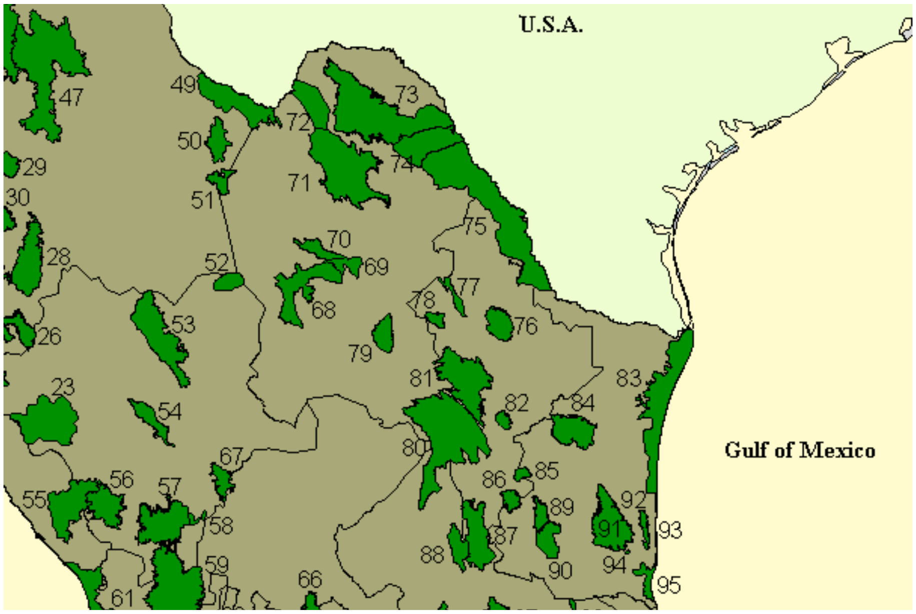


Source: Conabio-Conanp-TNC-Pronatura, 2007.

- The area is considered a Priority Terrestrial Region in Mexico (Fig. 8), due to its importance as a biological corridor and because the region functions as a transition zone of the Nearctic fauna linked to wetlands.
- The region constitutes one of the most important migratory routes for birds (Mississippi and Central Flyways) (Figs. 9 and 10) (DOF 2005;

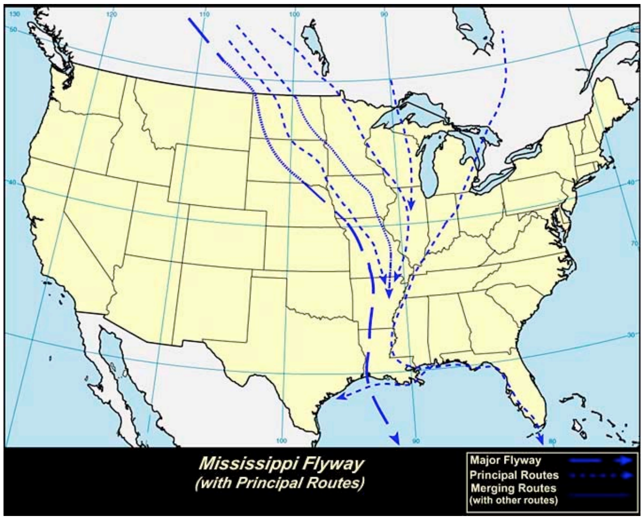
BirdNature 2009). Indeed, it is a migration site for more than 450 species aquatic, semi- aquatic and terrestrial birds and the wintering site for 15% of all the migratory birds arriving to Mexico from Canada and the US, providing refuge, food and permanent nesting for 144 bird species, 2.7% of which are endemic to Mexico (DOF 2005).

Figure 8. Priority Terrestrial Regions in Mexico



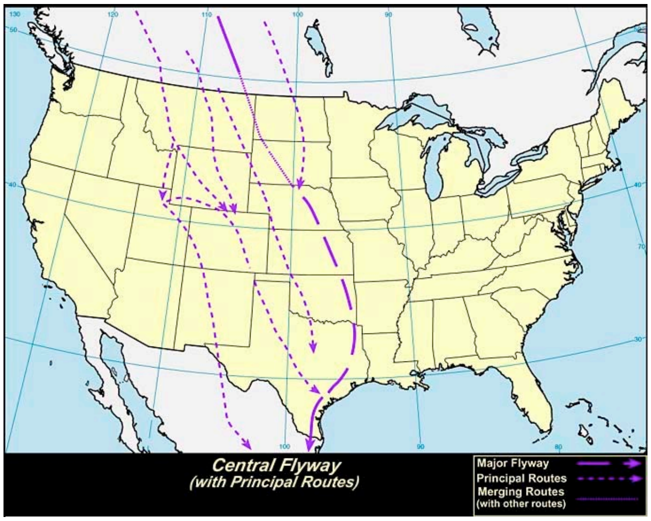
Source: Arriaga Cabrera et al., 2009.

Figure 9. Mississippi Flyway



Source: North American Migration Flyways, <http://www.birdnature.com/flyways.html)>.

Figure 10. Central Flyway



Source: North American Migration Flyways, <http://www.birdnature.com/flyways.html>.

- Due to these facts, the area is regarded as the first priority wetland (among 28) for migratory birds in Mexico by Ducks Unlimited (Ramsar 2009), as well as an Important Bird Conservation Site (Áreas de Importancia para la Conservación de las Aves, AICA) (Conanp 2006).
- Among the different bird species inhabiting the region are 26 species of anseriformes (68.42% of the species distributed in Mexico), among which are found a significant number (an average of 245,000 individuals) of redhead duck (*Aythya americana*) (36% of the world's population) and internationally important concentrations of ruddy duck (*Oxyura jamaicensis*). The Laguna Madre also holds nearly 50% of the reddish egrets (*Egretta rufescens*) migrating to Mexico and the only reproductive colony of the white pelican (*Pelecanus erythrorhynchos*) in the coastal environments of Mexico. It provides a site for the congregation of 100,000 seashore birds representing the highest concentration in the country, as well as ducks and geese that reach their southernmost distribution (Pérez-Arteaga et al. 2002; DOF 2005; Conanp 2006).
- The region also represents a critical habitat for the distribution of the endangered (NOM-059) piping plover (*Charadrius melodus*), as 6% of the total population overwinters in specific areas of the costal barrier of the Laguna Madre (Conanp 2006).
- Since 2000 five areas within the region (Laguna Atascosa National Wildlife Refuge, South Padre Island Preserve, Rancho Rincón de Anacahuitas, Padre Island National Seashore and Flora and Fauna Protected Area-Laguna Madre and Rio Bravo Delta) have been

recognized as Sites of International Importance by the Western Hemisphere Shorebird Reserve Network (WHSRN 2009).

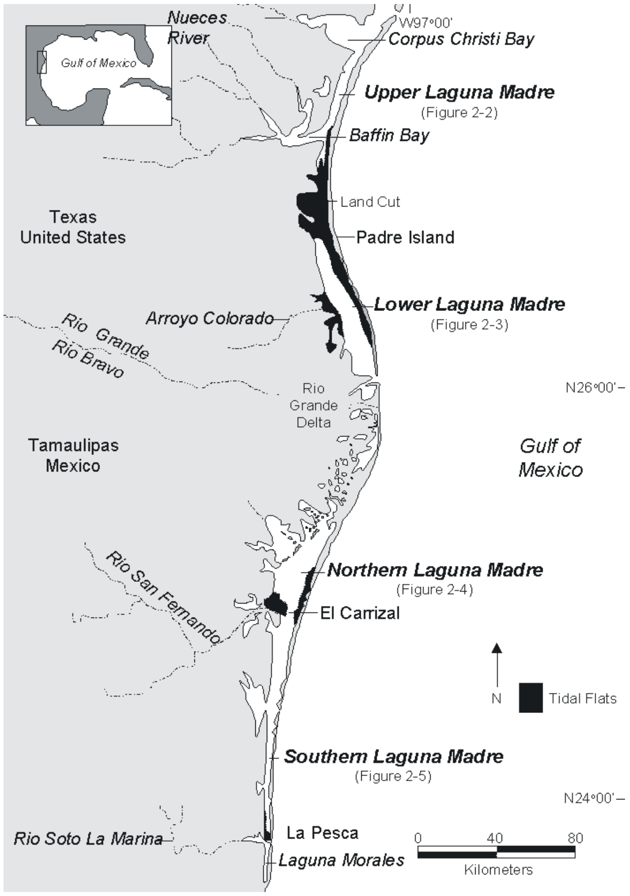
- The Río Bravo/Laguna Madre Ecoregion has close links with other CEC PCRs, such as Region 13 (Maya Reef and South Florida Coastal Marine System) Laguna Madre has been identified as a “crucial hotspot” area for priority natural resource protection and conservation projects by the US Department of Interior and Semarnat, the Mexican national environmental and resource conservation agency (Good Neighbor Environmental Board 1998).
- In addition to these best-known features of the Laguna Madre, there are other unique, less well-known, but important characteristics, such as: the most extensive wind-tidal flats and clay dunes in North America; the only strain of high- salinity-adapted oysters in North America, and in Texas, the only natural rocky shoreline, the only serpulid worm reefs, and the only formations of oolite (*Calcium carbonate*) and gypsum crystal.

Laguna Madre

Geography

The Laguna Madre is naturally divided into two segments by a 20-km-long (12-mi-long) expanse of seldom-flooded sand and mudflats (Fig. 11). The Upper Laguna Madre extends 80 km (50 mi) northward from the flats to its terminus in the southeast corner of Corpus Christi Bay and ranges in width from 3 to 6 km (~2 to 4 mi), while the Lower Laguna Madre extends 95 km (59 mi) southward from the flats to within 5 km (3 mi) of the Mexican border and ranges in width from 3 to 12 km (~2 to 7 mi).

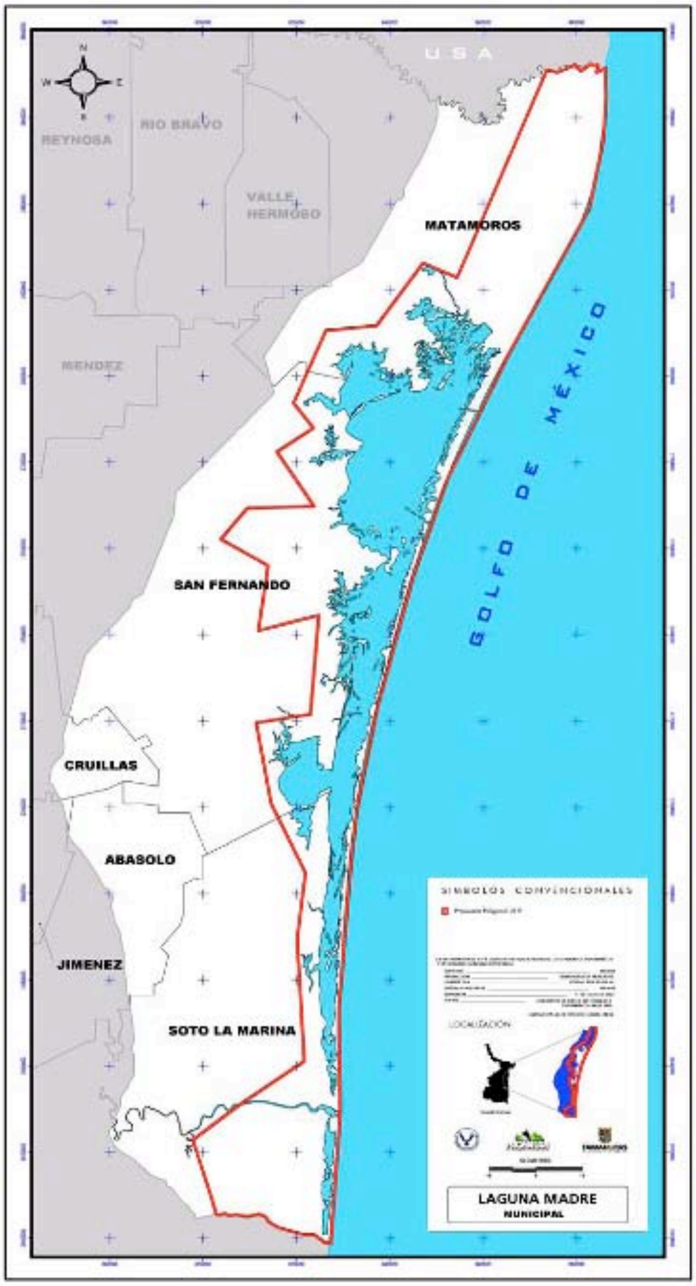
Figure 11. The Laguna Madre of Texas and Tamaulipas



Source: Tunnell y Judd, 2002.

The Laguna Madre of Tamaulipas is located on a coastal plain of the Gulf of Mexico (Fig. 12), set 120 km west of Ciudad Victoria, the state capital. It is located within the Nearctic Region inside the province of the northeastern coast. North to south, the Laguna Madre is parallel to the coastline and is bordered by a sandbar 223 km long, it has an approximate width of 3 km in the South and 30 km in the North.

Figure 12. Municipalities Included in the Laguna Madre of Tamaulipas Natural Protected Area



Source: Pronatura, UAT, Conanp, 2002.

The Laguna Madre ecosystem encompasses some 2,028 square kilometers (738 square miles) of diverse habitats extending for 185 kilometers (115 miles) along coastal northern Tamaulipas. Included in this protected area are the Río Grande Delta at the lagoon's northern end and Laguna Morales at its southern end—for a total of 485,647 hectares (1,200,000 acres) and its barrier islands.

Origin, Development and Geology

According to radiocarbon dating, the Laguna Madre began forming about 5,000 to 4,500 years before present (YBP) as post-glacial sea level rise slowed and offshore sandbars (like Padre Island) began to develop; the lagoon became enclosed about 2,800 to 2,500 YBP. Hypersaline conditions apparently developed in Baffin Bay first, as long as 5000 to 4300 years before present.

The Rio Grande Delta divided the Texas and Tamaulipas lagoon into two systems during the late Pleistocene and early Holocene. Important geological or biogeological features include extensive wind-tidal flats and clay dunes, localized beach rock (coquina), serpulid worm reefs, and geochemically-precipitated oolites (calcium carbonate) and gypsum crystals and rosettes.

Population

Five counties with a population of 637,228 people surround the Texas lagoon and three counties, with 499,784 inhabitants reside around the lagoon in Tamaulipas. Population centers along the shores of the Laguna Madre include six cities and towns in Texas with 277,631 people; in Tamaulipas, there are 34 towns and villages with a population of 9,738 people on the lagoon shoreline, and another 1,354 people living on the islands within the lagoon.

Climate

The regional climate is classified as semiarid or subtropical steppe (also as subhumid- to-semiarid east-coast subtropical climate), with extreme variability in precipitation and an evapotranspiration two to three times higher than precipitation. Persistent southeasterly winds dominate throughout the year, interrupted by strong northerly winds in the winter; humidity and temperatures are high, and tropical storms or hurricanes may cause major changes to the system.

The climate of the Laguna Madre area is varied, and belongs to two major climate groups (according to Köppen's system modified by García): The Northern part of the Laguna is classified as climate (A)Cx', temperate semi-warm subhumid with scarce rains during the year. The central part is classified as climate BS1(h')hw, dry, semi-dry very hot and hot with summer rains. The southern part is classified as climate (A)C(wo) temperate, semi-warm with summer rains, the percentage of winter rains is between 5% and 10.2%. The average annual precipitation is 682 mm.

Water Cycles

The commonly recorded extreme salinities of over 100 ppt in both systems have been moderated in recent decades due to changes in water circulation [in Texas, Gulf Intracoastal Waterway (GIWW) in 1949 and Mansfield Pass in 1962, and in Tamaulipas, four dredged, jettied passes connecting the Gulf with the lagoon in Tamaulipas in the 1970's].

In Tamaulipas, before the 1970s, a "boom and bust" cycle due to hurricane flushing would cause great fishery production to alternate with briny, almost sterile waters. The cycle included a highly productive lagoon for several years after a wet hurricane, followed by dwindling fisheries and species diversity as the barrier island passes closed and the completely enclosed lagoon progressed towards higher and higher salinities. During extended droughts, or long periods between hurricanes, the lagoon began to dry up with water level decreasing and salinities increasing due to evaporation. When salinities reached 150 ppt, only brine shrimp existed, and at the highest recorded salinity of 295 ppt, salt had precipitated along the shoreline and in the bottom of the lagoon. Then a hurricane would open Gulf passes, flush the system with floodwaters from rain, and the cycle would begin again. Major hurricanes in 1909, 1933, and 1967 all demonstrated this cycle in Tamaulipas, and it is likely that a similar cycle existed in Texas before channelization of that system (GIWW completed in 1949, Mansfield Pass completed in 1962).

Hydrography

No rivers drain into the Texas lagoon and only one, Rio San Fernando (also known as Rio Conchos), enters the Tamaulipas lagoon. Besides this little freshwater inflow the Laguna Madre hydrography is characterized by a high evaporation, low tidal range and shallow bathymetry, all of which contribute to its characteristic hypersalinity.

Salinities have dwindled due to human-induced hydrologic alterations in both systems. Prior to completion of the Gulf Intracoastal Waterway (GIWW) in 1949, a 20-km (12-mi) reach of emergent sand and mudflats had divided the lagoon into separate basins, which were connected only under conditions of extreme high water. Now the GIWW provides a permanent water connection between upper Laguna Madre and lower Laguna Madre. This hydrological connection, together with currents produced by prevailing winds oriented along the long axis of the lagoon, improved circulation between basins and with the Gulf of Mexico and moderated the extent to which lagoon waters became hypersaline. Since completion of the waterway, salinity never rises much above 50 ppt.

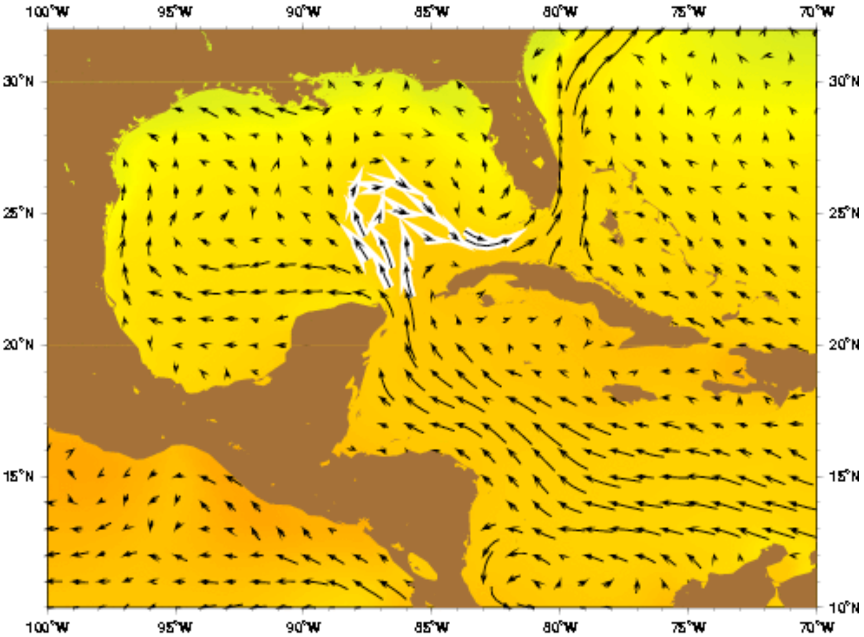
Circulation and Currents

Water from the Yucatan Current and the Florida Current enters the Gulf through the Yucatan Strait, circulates in clockwise manner as the Loop Current around the Gulf of Mexico (Fig. 13), and exits through the Florida Strait, eventually forming the Gulf Stream. Portions of the Loop Current often break away, forming eddies or 'gyres' which affect regional current patterns. Smaller wind driven and tidal currents are created in the nearshore environments (Gore 1992). The Loop Current is variable in position. At one extreme, it has an almost direct path to the Florida Current, causing the shear in the flow to set up a quasi-permanent clockwise recirculation known as the Cuban Vortex. This feature may help initiate Loop Current expansion. At the other extreme, the Loop Current intrudes into the Gulf of Mexico, forming an intense clockwise flow as far north as 29.1N. Occasionally this loop will reach as high as the Mississippi River delta or the Florida continental shelf. The Loop Current returns to its direct configuration by slowly pinching off its extension to form a large, warm-core ring that then propagates westward at speeds of 2-5 km/day. The 900 km expanse of Loop Current position is reminiscent of the variability in position at the Gulf Stream Extension region (Gyory et al. 2009).

The Loop Current feeds the Florida Current that transports significant amounts of heat poleward; transports surface waters of tropical origin into the Gulf of Mexico; and is fed by the Caribbean current and the Yucatan Current (Gyory et al. 2009).

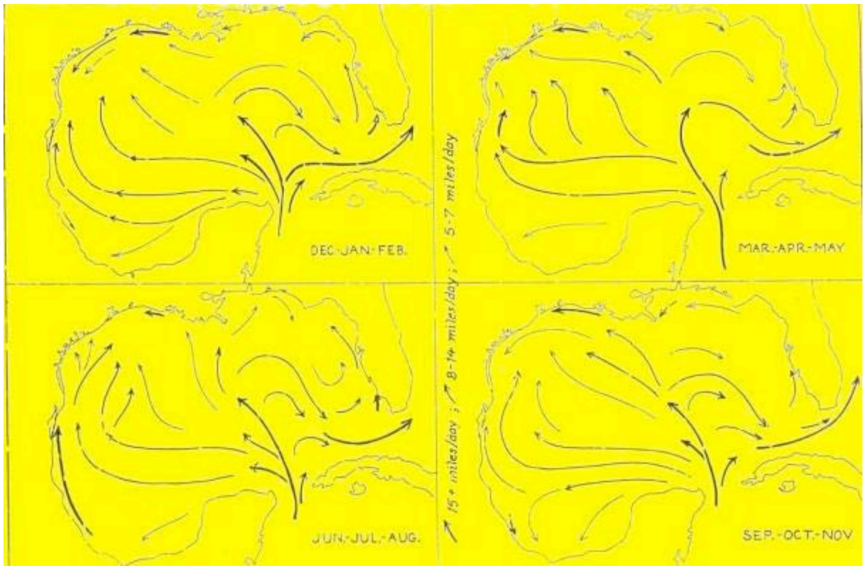
The prevailing set of inner coastal currents is westward and southward, or counterclockwise, in the northwestern part of the Gulf at least to Big Shell on Padre Island, where there seems to be a convergence with a northward current along the shore. If the currents of the Gulf of Mexico as a whole are summarized by quarters, seasonal differences are apparent (Fig. 14). These are most pronounced in the northeastern part. The currents a few miles off the Texas coast set northward during the summer quarter, and this northward set is evident also in the spring quarter. Pronounced differences in surface and bottom currents in shallow water near shore are experienced by commercial trawlers at some times, especially during the summer months, the reverse directions of surface and bottom currents make trawling difficult (Heppeth 1953).

Figure 13. Currents in the Gulf of Mexico



Source: Heppeth, 1953.

Figure 14. Currents in the Gulf of Mexico, by Quarters



Source: Heppeth, 1953.

Hurricanes

Available literature indicates that hurricanes do not generally produce long-term detrimental impacts to unmodified coastal systems and that they often provide net benefits along the U.S. Gulf Coast. While there is normally initial erosion from hurricanes, they also often result in a large influx of inorganic sediments, creating new wetlands and contributing to the maintenance of existing wetlands. The formation of washover deposits is disastrous where cultural development has occurred, but in natural areas, as in the case of the Laguna Madre, these deposits are part of the natural cycle of shoreline development and contribute to habitat diversity and productivity. Rainfall during tropical disturbances accounts for significant part of total precipitation along the northern gulf. The immediate impact of hurricanes may be to reduce populations of some species but these populations generally recover rapidly. Overall, productivity in natural systems seems to be increased by periodic hurricanes. Hurricane impacts are often severe and long lasting in wetlands that have been modified by human impacts such as semi- or complete impoundments.

Since 1900, forty major hurricanes have crossed the Gulf Coast (from Texas to the Florida Panhandle). Seven were of category four (1900, 1919, 1915 (2), 1932, 1957, 1961). Hurricane Frederic (1979) and Hurricane Katrina (2005) were close to category four at landfall. Only one category five hurricane has ever struck the Gulf coast—Camille in 1969. There have been two significant periods of heightened tropical cyclone activity in the Gulf states. The first peak occurred from 1900 to 1920, when eleven major hurricanes crossed the Gulf coast. The second peak occurred from 1960 to 1980, when ten major hurricanes crossed the Gulf coast.

Hurricanes that impact the Gulf states usually approach the region through the northwestern Caribbean Sea. Some of the largest and most intense hurricanes to strike the Gulf coast originate thousands of miles away in the deep tropical Atlantic. Many storms that impact the Gulf states, also develop in the Gulf of Mexico itself. Hurricanes that strike the Florida Atlantic coast, occasionally pass completely over the peninsula—and strike one of the Gulf states. When this occurs, Louisiana or Texas are the preferred targets. Hurricane Andrew in 1992 was a recent example of this (US Hurricanes Information 2009).

The 1900 Galveston Hurricane, Hurricane Camille (1969), and Hurricane Katrina in 2005 (Fig. 15) are the three most devastating tropical cyclones to strike the Gulf coast over the last one-hundred ten years.

Figure 15. Image of Hurricane Katrina

Source: National Hurricane Center, http://www.nhc.noaa.gov/.

Tamaulipan Biotic Province

The Tamaulipan Biotic Province exhibits greater faunal diversity than any other biotic province in the state of Texas. This Biotic Province is important as a dispersal route for tropical species moving northward and for temperate forest and grassland species moving southward. Despite its biodiversity value it has suffered serious human perturbations; for example, since the 1920s, more than 95% of the original native brushland in the lower Rio Grande Valley has been cleared and converted to agricultural and urban use.

Ranching Heritage

Vast South Texas ranches, like the King Ranch and Kenedy Ranch, have afforded protection to the mainland Laguna Madre shoreline (and thus the Laguna Madre) by not allowing access or development; similar conditions, like Rancho Rincón de Anacahuitas, exist in Tamaulipas.

The Ecosystem

The Laguna Madre is characterized as a negative estuary or hypersaline lagoon. Hydrologic alterations in water circulation (dredged channels and passes) have changed the ecosystem from excessively hypersaline (over 100 ppt) to moderately hypersaline (40-80 ppt).

The food web of the Laguna Madre is predominantly based on submerged aquatic vegetation (seagrass and algae), rather than free-floating phytoplankton.

The ecosystem in Texas is dominated by seagrass habitat in the lagoon and wind-tidal flats along the shore. However, in Tamaulipas, a bare bottom predominates over seagrass meadows in the lagoon, and wind-tidal flats, although not as common as in Texas, dominate over emergent marsh shorelines.

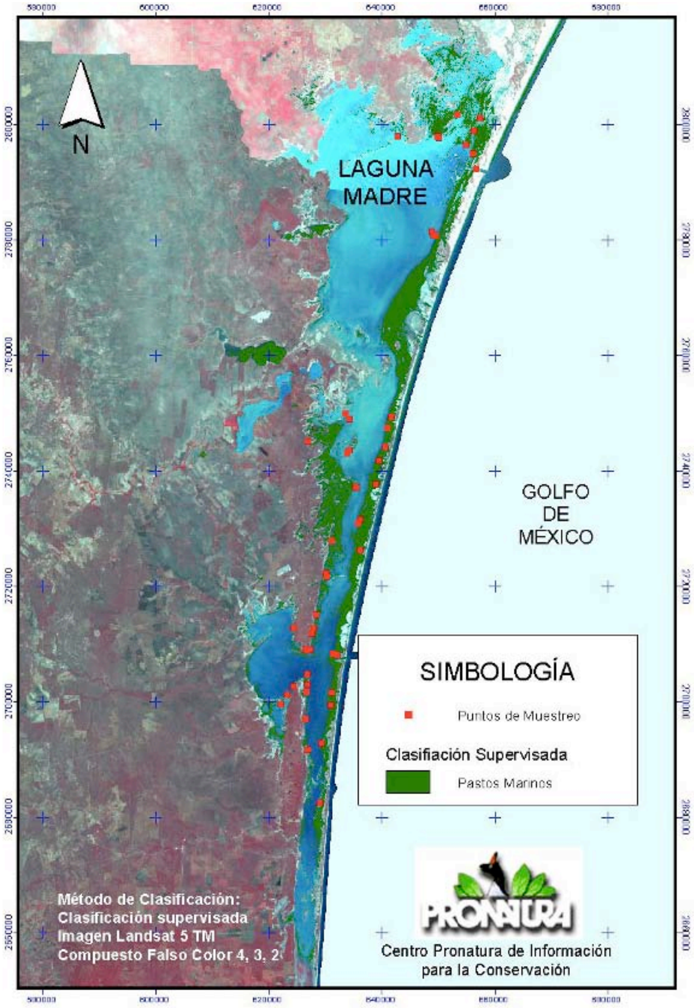
Aquatic biodiversity of Laguna Madre appears to be only 35 to 45% of those of the normal or positive estuaries to the north, with 938 species from upper Laguna Madre and Baffin Bay, and 706 species from Laguna Madre de Tamaulipas, compared to 2,043 species from the Texas Coastal Bend (three estuaries). The Tamaulipan lagoon, however, is less studied and may indeed be more diverse than is currently known because of the presence of more tropical species there.

Seagrass Meadows

A variety of circumstances act together to make the Laguna Madre a hospitable environment for seagrasses. The average depth of the lagoon is 1 m. Although the mapped watershed of the lagoon is more than 15 times the water area of the lagoon, the surrounding land is so flat and precipitation so low that most of the watershed does not actually contribute to the lagoon. Consequently, there is little inflow of nutrients or suspended particles, and the waters of the lagoon are generally clear.

Among the native seagrass species, shoalgrass (*Halodule beaudettei*) is predominant, with lesser amounts of wigeon grass (*Ruppia maritima*), clover grass (*Halophilia engelmannii*), turtle-grass (*Thalassia testudinum*) and manatee-grass (*Cymodocea filiformis*). The last species is not found in the Laguna Madre of Tamaulipas instead, seagrass from the genus Syringodium is present. However, species distribution throughout the region is very dynamic and shifts in composition occur (Fig. 16).

Figure 16. Seagrass Distribution in Laguna Madre of Tamaulipas



Source: Pronatura-UAT-Conanp, 2002.

Seagrass meadows are extremely valuable habitats that provide complex structure in the water column and sediments. This structure is important because it supplies nursery areas, refuge, and rich foraging grounds for a variety of estuarine fish and invertebrates, including species of commercial and recreational importance. The seagrasses, such as the shoalgrass meadows in Texas and Tamaulipas, are also essential winter foraging habitats for migrating birds. For instance, an estimated 77% of the North American Redhead population winters on the Laguna Madre. During winter, redheads feed primarily (>80% of their diet) on rhizomes of shoalgrass (Custer et al. 1997).

The concentration of Texas seagrass distribution in the Laguna Madre (79%) is a result of geographic and climatic factors. Increasing coverage and changing species composition in the Texas Laguna Madre over the last 30 years has resulted from lower salinity, due to construction of GIWW and Mansfield Pass. From the mid-1960s to 1998, the area of vegetated bottom decreased 2,856 ha (7,057 acres) (4%) for the lagoon as a whole. The percent cover of turtle grass has increased from being barely present to dominating 11% of the lagoon bottom, and manatee grass first increased from 6% to 17% but then fell back to 14%. All of these increases were at the expense of shoal grass, which covered 64% of lagoon bottom in the earliest survey but had diminished to 40% by 1998. Between 1965 and 1974, 118 km^2 (46 mi^2) of vegetated bottom became bare. Following the observation that the new unvegetated bottom could be related to the GIWW and the adjacent naturally deep parts of the lagoon, it has been suggested that the reduced light resulting from turbidity caused by maintenance dredging of the waterway was likely responsible for the loss of seagrass.

Wind-Tidal Flats

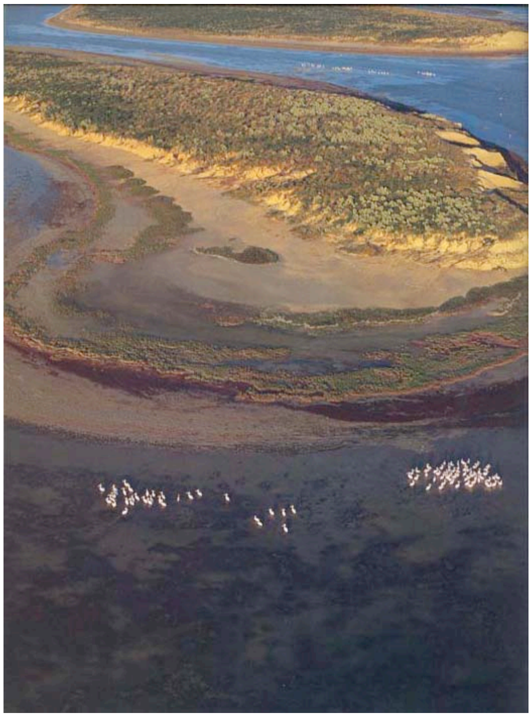
Wind-tidal flats cover over 1,440 km^2 (550 mi^2) of land adjacent to Laguna Madre in Texas and Tamaulipas, occupying 917 km^2 (354 mi^2) of shoreline in the Texas Laguna Madre and 508 km^2 (196 mi^2) in Tamaulipas. Clay dunes form a mainland transition zone between the wind-tidal flats and the upland in many areas. Flooding and exposure of wind-tidal flats is unpredictable because they are caused by wind-tides rather than astronomical tides. Wind-tidal flats are much more productive than they appear. They convert plant biomass to animal biomass where the water meets the land, filling the role marshes play in less arid climates. The wind-tidal flats of the Laguna Madre represent the largest continuous expanse of suitable wintering habitat for shorebirds between northern breeding grounds and more distant wintering grounds in South America. They are vital to several federally protected birds including the Piping Plover. Dramatic losses in the aerial extent of wind-tidal flats since the 1950s are largely due to global sea-level rise, but human impacts have also been a contributing factor.

Barrier Islands

Over 200 natural islands exist in Laguna Madre de Tamaulipas and fewer than 10 exist in the Texas lagoon (Tunnell et al. 2002), although hundreds of dredged material islands are present.

Barrier islands are dynamic landforms that protect the Laguna Madre and provide habitat for resident and migratory species, including the peregrine falcon and snowy and piping plovers (Fig. 17).

Figure 17. Barrier Island in the Laguna Madre of Tamaulipas



Source: Cantú *et al*., 2005.

There are two barrier islands protecting the Texas Laguna Madre: Padre Island, extending the entire length of the Laguna Madre of Texas, is the longest barrier island in the world, and Brazos Island (now a peninsula). In Tamaulipas, there is one peninsula, Barra el Conchillal, and three barrier islands, Barra Los Americanos, Barra Jesús María and Barra Soto la Marina, protecting the Mexican lagoon. Barrier island beaches provide nesting habitat for the federally protected Kemp's ridley, Atlantic hawksbill, loggerhead and green sea turtles. Island dunes are instrumental in protecting the mainland from storms and hurricanes.

Vegetation zoning is similar for barrier islands in Texas and Tamaulipas, although vegetated areas become less extensive further south. Barrier islands along southern Texas and the northern Tamaulipas coast are elongated in shape and typically wider at their northern end. Several habitat types occur along the islands and are related to elevation, physical forces, and the geomorphology of the adjacent Gulf of Mexico and lagoons. Physiographic zones extend the island length and include foreshore (swash zone), backshore (from the high tide line to the dunes), foredunes, vegetated flats with ponds and marshes, and wind-tidal flats with back island dunes and coastal marshes in some places. Foreshore habitat, wind-tidal flats, and coastal marshes are affected more by hydrologic and eolian forces than are terrestrial dunes and vegetated flats. Ponds and marshes in vegetated flats form an integral component of the ecological relationship of barrier island systems.

A unique island profile begins north of Mesquital and extends southward to Boca Ciega Pass, where coppice dunes (lower dunes seaward of foredunes) vegetated with sea purslane (*Sesuvium portulacastrum*) prevail across most of the island, extending from 1 to 3 km wide. Large, unvegetated dunes 13-15 m high are located near the lee side of the peninsula of the barrier island, covered by shrubs (primarily mesquite) and grasses, e.g., gulf cordgrass (*Spartina spartinae*). Foredunes are less vegetated from north to south in Texas due to lower average precipitation rates. Coppice dunes typically have low, spreading vegetation that collects sand migrating up the beach face (Smith 2002).

Both natural and artificial passes through the barrier islands provide tidal exchange between the Gulf of Mexico and the lagoons. There are two jettied passes in Texas, Mansfield Pass and Brazos Santiago Pass, which connect the lagoon with the Gulf of Mexico. There are four passes in Tamaulipas, El Mesquital, Boca Ciega, Boca el Catán, and Boca de Santa Isabel.

Birds

The Laguna Madre in Texas and Tamaulipas contains some of the largest expanses of undisturbed wetland complexes in the Western Hemisphere and is one of the most significant coastal areas for aquatic bird life on the entire coast along the Gulf of Mexico. As a result, it is part of the Western Hemisphere Shorebird Reserve Network. Large numbers of migrating and wintering shorebirds use wind-tidal flats and barrier beaches; smaller numbers use various other emergent habitats such as washover passes and coastal wetlands.

Several species of colonial waterbirds inhabit the Laguna Madre: twenty-three species of herons, egrets, ibises, pelicans, terns, gulls and skimmers. Twelve species of colonial waterbirds were documented in northeastern México rookeries. The only major American White Pelican coastal colony exists in upper Laguna Madre of Texas, with a smaller nesting population documented in Laguna Madre de Tamaulipas. The largest concentration of reddish egrets in the world can be found in the Laguna Madre. Shorebirds such as Wilson’s plovers and snowy plovers nest here, or scurry after small prey in the tidal flats surrounding the Laguna. A large percentage of the population of federally threatened piping plovers winters in the Laguna Madre. The region’s grasslands and barrier islands are also some of the world’s most important fall and spring stopover areas for the peregrine falcons. The Laguna Madre is the primary wintering destination for Redhead ducks. As mentioned above nearly 80% of the North American population use shoalgrass meadows and other habitats within the lagoons as well as nearby coastal ponds on the mainland in both Texas and Tamaulipas. Decreases in water flow into the Rio Grande Delta from the river have reduced available wetland habitats. Climatic extremes in northern Tamaulipas determine amount and quality of habitat for waterfowls. An extended drought occurred from 1945 to 1951, limiting the amount of freshwater inflow to coastal bays and lagoons and reducing water levels in freshwater ponds. Although precipitation in 1952 was higher, the following year was very dry. Little flow was observed in the Rio Grande and many basins where waterfowl usually wintered were dry. In 1954 rainfall increased and habitat improved slightly. Several months of rainfall in 1955 increased habitat availability, and hundreds of wetlands in the Rio Grande were filled with freshwater. A population increase to 30,000 ducks was recorded that year, as compared to only 2,500 in 1954 (Smith 2002). These changes in precipitation and habitat availability continue to this date.

Fish and Fisheries

Fish biodiversity appears to be greatest in the Laguna Madre of Tamaulipas with 122 species, compared to 79 in the upper Laguna Madre and 67 in the lower Laguna Madre (the Tamaulipas lagoon has more tropical species; the lower Laguna Madre in Texas needs more research). Thirty-seven of the 44 fish and invertebrate species found within the Laguna Madre of Texas have been recognized by the National Oceanic and Atmospheric Administration's Estuarine Living Marine Resources Program as having ecological, commercial or recreational value, or importance as an indicator species of environmental stress.

The Upper Laguna Madre is the primary spawning ground for black drum (*Pogonias chromis*) along the Texas coast. Also, just south of Baffin Bay, Penascal Point provides critical habitat for the hairy blenny (*Labrisomus nuchipinnis*), crested blenny (*Hypleurochylus geminatus*), and gray snapper (*Lutjanus griseus*). Primary native fishery species of Laguna Madre include red drum, black drum, spotted seatrout and penaeid shrimp; the Texas fishery has historically been of commercial importance but is also recreational. The average annual sport and commercial harvest of fish and shellfish seafoods is estimated at 7.3 million pounds (3.3 million kg; 12 percent shellfish). At this level of fishing activity, the total annual economic impact is estimated to be $40 million. The Laguna Madre constitutes about 20 percent of Texas' protected coastal waters but has historically contributed 40 to 51 percent of the State's commercial fish catch (Onuf 2007).

As mentioned before in the section on water cycles, the Tamaulipas fishery was cyclically "boom and bust" because of hurricane flushing, but now is more stable now that the passes to the Gulf have been dredged.

The Laguna Madre of Tamaulipas is divided into two hydrographic units by the shallow mud flats off the mouth of the Rio San Fernando. The northern part is usually a brine pool but intermittently the environment becomes highly productive when diluted by runoff from the Rio Bravo and repopulated by fishes moving through the reopened barrier island passes. The black drum, *Pogonial cromis,* is the principal commercial species. The southern part is more variable in its salinity ranging from nearly freshwater to a series of brine pools, but it is usually hypersaline. There were extensive meadows of shoal grass, *Diplanthera wrightii*, in which lived large populations of palaemonid and juvenile penaid shrimp. The importance of the speckled seatrout, *Cynoscion nebulosus*, and the red drum, *Sciaenops ocellatus*, is apparent from catch statistics for several years.

During the winter months, these waters supported a large population of brine shrimp, *Artemia salina*. Hurricanes would reopen the passes and produce torrential rains, lowering salinities to brackish levels and allowing repopulation of fish and invertebrate species from the sea. Major hurricanes of 1909, 1933, and 1967 all demonstrated this cycle in Tamaulipas, and it is likely that a similar cycle existed in Texas before channelization of that system (GIWW was completed in 1949, Mansfield Pass in 1962) (Tunnell et al. 2002).

The fish entering supersaline areas are euryhaline estuarine species, which seem to become more easily adapted to hypersaline conditions than fishes that live in the more constant salinities of seawater. Occasionally, extreme conditions exist when the salinities reach an equivalent of about 100 ppt and all animals die. When this happens, populations are re-established from nearby estuarine waters. Fish and shrimp captures in the Laguna Madre of Tamaulipas were very significant in the early 1990s (up to 20,000 metric tons) and are currently estimated at 41,000 tones, with an approximate value of $786 million Mexican pesos (around 60 million 2009 US dollars).

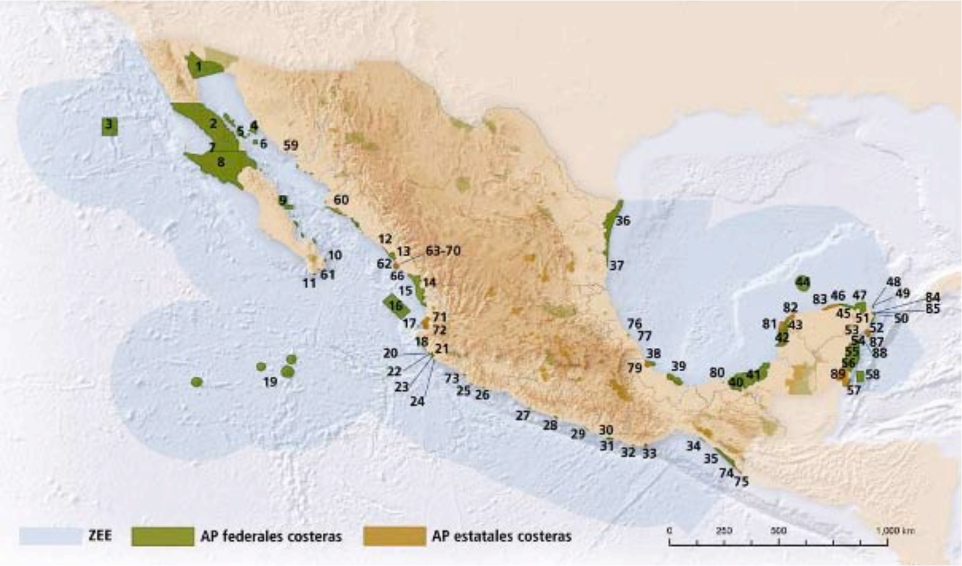
Conservation Issues

Critical issues of concern needing (and in some cases receiving) attention are Arroyo Colorado water quality. The Lower Laguna Madre receives significant quantities of agricultural pesticides and other environmental contaminants from the Arroyo Colorado, and irrigation drainage from the Lower Rio Grande Valley. Other significant problems are dredge material placement, barrier island development and habitat loss, brown tide, and seagrass impacts in Texas, and island-living impacts, agricultural contaminants, land management and protection in Tamaulipas. As a consequence, more than 60% of native flora and fauna have disappeared in the latter region.

Anthropogenic issues or concerns include island inhabitation impacts, channelization, dredge material placement, artificial passes, contaminants, seismic impacts, seagrass scarring, and trash/debris. Oil spills from barges, discharge from the Mexican side of the Rio Grande, and hydrocarbon extraction are the threats posed by the high volume of commercial activities taking place on the Laguna Madre. Accidental and deliberate releases of exotic shrimp or effluent from commercial shrimp farms are also a concern.

In 2005, Mexico declared the entire Laguna Madre of Tamaulipas as a natural protected area (NPA) (Fig. 18). This designation is a milestone in the conservation of such a productive and diverse estuary. This designation, by itself, will not safeguard the lagoon from all the problems affecting it; however, it represents the commitment from the Mexican government towards more environmentally sound management practices.

Figure 18. Federal and State Coastal Natural Protected Areas in Mexico

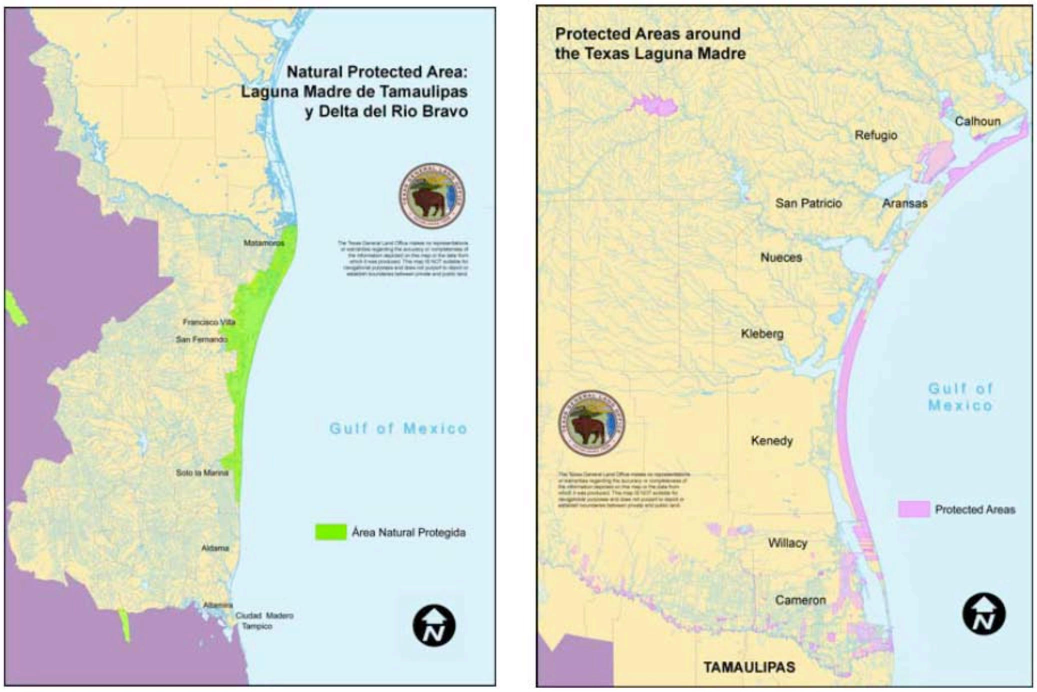


Source: Conabio-Conanp-TNC-Pronatura, 2007.

Since 1998, the Coastal Bend Bays and Estuaries Program (CBBEP) has served as a tool complementing the Texas Coastal Management Program in the protection and management of the Upper Laguna Madre in Texas. The CBBEP was created after the designation of the Coastal Bend bay systems as an “Estuary of National Significance” and part of the National Estuary Program. However, it does not cover the entire Laguna Madre. In addition to the CBBEP, the Padre Island National Seashore, the Laguna Atascosa National Wildlife Refuge and the private ranches along the coast have contributed to the protection of the Laguna Madre.

The Mexican designation of the Laguna Madre as a NPA clearly shows that the concept of sustainability does not mean that a protected area must be a sanctuary, but rather an area where human activities are balanced with the protection of natural resources to ensure their mutual, long-term viability (Fig. 19).

Figure 19. Natural Protected Areas in the Laguna Madre of Texas and Tamaulipas



Source: Barraza y Calnan, 2006.

Threats

While the estuaries and shallow coastal habitats of the Gulf of Mexico ecoregion are rich and productive because they receive inputs from terrestrial, freshwater, and marine sources, they are also susceptible to the different stresses disturbing all these environments. A stress is something that impairs or degrades the size, condition or landscape context of a conservation target and therefore reduces its viability. Considering this ecological richness it is essential that ecosystems do not become stressed beyond the threshold at which undesirable and irreversible changes will set in. However, recent concerns about increasing human activity have focused attention on the long-term health of the Laguna Madre as growing population pressures, pollution problems and dredging threaten this unique ecosystem.

Other pressures have being intensifying these threats, such as the impacts caused by agriculture and livestock, effects of aquaculture and fisheries, *nutrification, impact through regional development, the increasing probability of introductions of exotic species at a regional level due to the intense commerce from outside the region and synergies with other threats. The principal sources of stress on the Mexican side of the Laguna Madre come from overfishing. On the Texas side, stresses arise mainly from nutrification and pollution, which come principally out of the Arroyo Colorado from agricultural, municipal, and shrimp aquaculture outflows. Direct and indirect target destruction on the Texas side arises from the dredging of the Intercoastal Waterway and from the use of all terrain vehicles (ATVs) on dunes and tidal flats.*

The following is a list of some common stresses and examples of their sources (Beck et al. 2000).

Indirect Target Destruction

Nutrification

Nutrification, an oversupply of nutrients (particularly nitrogen and phosphorous), can arise from many sources although in most sites around the northern Gulf of Mexico it occurs principally from agriculture with secondary inputs from municipal sources and aquaculture. Nutrification can have pervasive ecological effects on shallow coastal and estuarine systems. These effects include reduced water clarity, loss of aquatic habitat, algal blooms (toxic and non-toxic), and a decrease in dissolved oxygen (=hypoxia). Nutrification generally favors the growth of single-celled and small algae at the expense of macrophytes (like seagrass and marsh species), and when waters become hypoxic few animals that require oxygen can survive.

Light Attenuation

The distribution of submerged macrophytes (seagrasses and freshwater grasses) is closely tied to light availability. If light levels are reduced, the blade density of grass beds declines (i.e., thinning) and eventually the entire grass bed can be lost. Blooms of algae associated with brown tides are an important source of this stress. The source of these brown tides is an open question, but it is well known that they thrive in the presence of excess nutrients. Incompatible coastal development can increase water turbidity through direct runoff across hardened surfaces and indirect runoff from municipal wastewater. Trawling and heavy boat traffic in shallow water can suspend bottom sediments, which also reduces light availability. On a smaller scale, docks can attenuate the light that reaches the grasses underneath and around them.

Altered Water Chemistry (particularly salinity)

Many nearshore species are euryhaline, i.e., tolerant of a wide range of salinities. Nonetheless, long term changes in the mean and variability of salinity still affect the distribution and abundance of these species. This is clearly evident in the dynamic change in oyster and salt marsh distributions as salt water encroaches inland on this coast.

Altered Freshwater Hydrologic Regime

Alterations in freshwater flow (generally from freshwater diversions) change the basic characteristics of estuaries by altering the dynamic exchange between fresh and salt water. Changes in the volume and timing of freshwater inflow affect many important ecological processes, which control the abundance of many target species and habitats. Drivers include dams, levees, channelization and excessive surface and groundwater withdrawal.

Altered Salt Water Flow Regime

Changes in the flow of salt water principally affect tidal and wave energy and sediment transport. In many places shorelines are being armored by seawalls and similar structures, which reflect wave energy and lead to erosion of adjacent soft sediment habitats (e.g., marshes). Jetties and groins affect the long shore transport of sediments, changing the movements of barrier islands, causing sediment accretion in some areas and sediment loss in others.

Altered Sediment Regime

A major problem in several areas on the coast of the northern Gulf of Mexico comes from river modifications, particularly damming and channelization, which have substantially reduced the supply of sediments needed for the development of coastal marshes. Much of the coast of Louisiana is subsiding as older riverine sediments are compacted. This subsidence would normally be balanced by the accretion of new river-derived sediments, but the delivery of sediments out of the Mississippi River has been cut by 80% from historical levels.

Direct Target Destruction

There are many sources that contribute to the direct destruction of targets including: incompatible coastal development, dredging, inappropriate recreational use, invasive species and overfishing.

Incompatible Coastal Development

Incompatible coastal development (e.g., poorly designed homes, ports, docks, seawalls, golf courses, and marinas) has major direct impacts on habitats and species. This development also contributes to indirect target destruction by being a source of some of the other stresses identified in this section (e.g., altered flow regime, sedimentation, light availability, or nutrient source).

Dredging

Dredging also can destroy both habitat and organisms directly and indirectly.

Concerns about the impacts of dredges and towed fishing gear such as trawls on benthic habitats and organisms have increased over the last two decades. The reasons for this are that benthic habitats provide refuge for juvenile fish and the associated fauna that comprise important food sources for demersal fish (Lokkeborg 2005).

Otter trawls, beam trawls, and scallop dredges are likely to have different physical impacts on the sea bed, owing to their different catching principles. The most noticeable physical effects of otter trawling are the furrows (up to 20 cm deep) created by the doors, whereas other parts of the trawl create only faint marks. Beam trawling and scallop dredging cause a flattening of irregular bottom topography by eliminating natural features such as ripples, bioturbation mounds, and faunal tubes.

The most serious biological impacts of otter trawling on hard bottom habitats that are dominated by large sessile fauna were demonstrated when erect organisms, such as sponges and corals, were shown to decrease considerably in abundance at the passing of the ground gear. Experimental trawling on sandy bottoms of high sea (offshore) fishing grounds caused declines in some taxa. Studies of the impacts of shrimp trawling on clayey-silt bottoms have not demonstrated clear and consistent effects, but potential changes may be masked by the more pronounced temporal variability in these habitats. The long-term effects on fauna of beam trawling and scallop dredging have not been investigated, but several studies provide clear evidence of short-term effects.

Dredging for the Gulf Intracoastal Waterway and other smaller waterways is a significant cause of seagrass loss in the Laguna. It is known that dredging has caused increased water turbidity and eutrophication of coastal waters and increased water exchange with the Gulf of Mexico. However, debate continues on the impact of altered flow regimes on salinity within the Laguna. There is concern among Laguna experts that a continued decrease in salinity may jeopardize biologically and commercially important finfish and shellfish nurseries. In addition, improper placement of dredged material leads to reduced water circulation in tidal flats and the possible loss of those flats over time (TNC, NOAA, TCMP 2001).

Generally, the potential impacts of dredging and disposal can be summarized as follows:

- Removal of subtidal benthic species and communities.
- Short-term increases in the level of suspended sediment can give rise to changes in water quality that can affect marine flora and fauna both favorably and unfavorably, such as increased turbidity and the possible release of organic matter, nutrients, and/or contaminants—depending upon the nature of the material in the dredging area.
- Settlement of these suspended sediments can smother or blanket subtidal communities and/or adjacent intertidal communities.
- Depending upon the nature of the dredged material, its disturbance from the sea bed may lead to changes in the chemical composition of the water, e.g., many toxicants such as heavy metals and organic contaminants tend to stick to particulate matter and sink to the sediment. Some of these contaminants are very persistent in the

> sediment and some may change their oxidation state during burial, which alters their solubility. If the sediments are disturbed, the contaminants can be released to the water column and affect marine life.

Inappropriate Recreational Use

Inappropriate recreational use can also be a problem. Propellers of recreational boats are responsible for extensive scarring of seagrass, which affects nearly every shallow seagrass habitat in the northern Gulf of Mexico. In places with few remaining seagrasses, like the Mississippi Sound, even scarring from anchors can be a significant problem. All-terrain vehicles can destabilize dunes (particularly when driven on top of dunes) and degrade wind tidal flats.

Invasive species

Invasive species can also directly destroy competing native organisms through competition for substrate, competition for food or herbivory as well as predation upon the native species, or hybridization with them, and the disruption of numerous ecosystem processes.

Fortunately, there are currently relatively few invasive species that cause major problems in the northern Gulf of Mexico as compared to most regions (although the number of problem species is likely to grow). Submerged freshwater grass habitats are subject to substantial invasions from introduced macrophytes like the Eurasian milfoil, *Myriophyllum spicatum*, which commonly outcompete native species for space. Nutria, which was accidentally and then intentionally released in the 1930s and became unprofitable to trap for fur in the 1980s, graze on marsh plants and disrupt the substrate.

Overfishing

Overfishing can significantly alter population abundance and habitats. Trawl fishing (particularly for shrimp) can affect targets directly when they are taken as bycatch (e.g., turtles) and it can significantly impact habitats directly when the trawl scrapes them. The loss of some species like shellfish can, in turn, have system level effects on water clarity.

Inflow of Toxicants, Contaminants, and Pollutants

Overall, the level of these stresses from point sources has decreased, but inputs from non-point sources (e.g., septic systems and stormwater runoff) are on the rise (DeBlieu et al. 2005).

Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification.

Runoff pollution occurs every time rain or snowmelt flows across the ground and picks up contaminants. It occurs on farms or other agricultural sites, where the water carries away fertilizers, pesticides, and sediment from cropland or pastureland. It occurs during forestry operations (particularly along logging roads), where the water carries away sediment, and the nutrients and other materials associated with that sediment, from land that no longer has enough living vegetation to hold soil in place.

The control of point source pollution (any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged) has been improved through legislation and technology. Moreover, during the past 29 years, water pollution control efforts have focused primarily on certain process water discharges from facilities such as factories and sewage treatment plants, with less emphasis on diffuse sources. In contrast, the United States Environmental Protection Agency now considers pollution from all diffuse sources, including urban stormwater pollution, to be the most important source of contamination in US waters (EPA 1997). EPA ranks urban runoff and storm-sewer discharges as the second-most prevalent source of water quality impairment in US estuaries, and the fourth-most prevalent source of impairment of US lakes (EPA 1993).

Despite the fact that polluted runoff from agricultural sources may be an even more important source of water pollution than urban runoff, urban runoff is still a critical source of contamination, particularly for waters near cities. Within the Laguna Madre Ecoregion, many cities (Matamoros, Corpus Christi, etc.) have grown considerably during the last decades and as human activity increases in a given area, the amount of waste material deposited on the land and in drainage systems also increases.

The stormwater pollution problem has two main components: the increased volume and velocity of surface runoff and the concentration of pollutants in the runoff. Both components are directly related to development in urban and urbanizing areas. Together, these components cause changes in hydrology and water quality that result in a variety of problems, including habitat loss, increased flooding, decreased aquatic biological diversity, and increased sedimentation and erosion, as well as effects on our health, economy, and social well-being. The main reason why stormwater remains such an important contributor to water pollution is the fact that in most areas, stormwater receives no treatment before entering waterbodies. The storm-sewer system merely collects the urban runoff and discharges it directly to the nearest river, lake, or bay. Remarkably, studies have shown that stormwater alone can be almost as contaminated as sewage/stormwater mixtures.

Effluent from poorly maintained or failing septic systems can rise to the surface and further contaminate stormwater (EPA 1993). Septic systems are important sources of pathogens and nutrients, especially nitrogen, that are not effectively removed from the waste stream. Closures of bathing beaches and shellfish beds are frequently the result of septic system effluent entering bodies of water. For example, one study found that 74 percent of the nitrogen entering the Buttermilk Bay estuary in Massachusetts originated from septic systems. Fecal coliform and elevated BOD levels can be present in stormwater if the system is improperly sited, designed, installed, or maintained.

Global Warming

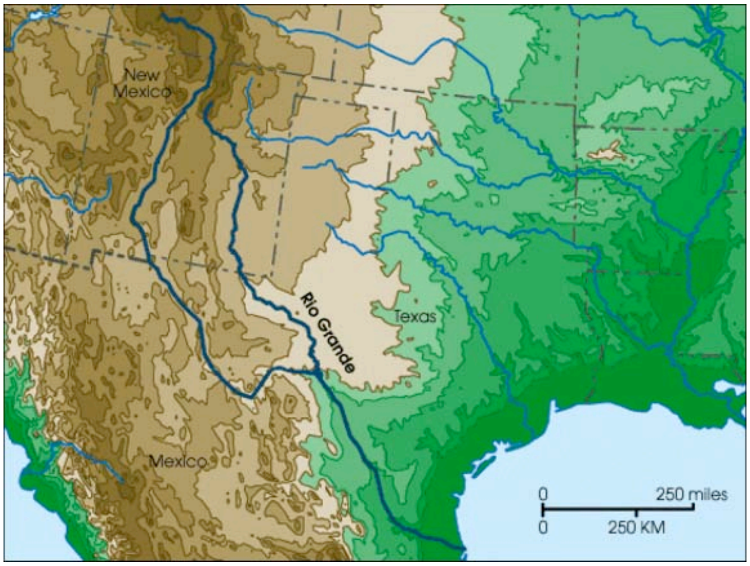
Global warming will compound these human pressures on the Laguna Madre, in some cases improving the situation, in others cases worsening it. For example, if future climate change brings a prolonged and more intense wet season to this region, the reliability of rainfall and soil moisture could improve. In wet periods, the land can retain rainfall and runoff, so wildlife and native plants increase their productivity, and the lagoon's salinity will be moderated. If rainfall decreases in the future, however, even a relatively small reduction in moisture could lead to increased desertification. Less freshwater delivery to the estuaries would worsen the losses already occurring in all types of coastal wetlands in Texas. Over the long term, such coastal wetland losses would in turn diminish estuarine-dependent fisheries.

Warmer winters are especially important from an ecological point of view. A northward shift of the freeze line would bring dramatic effects to the Coastal Bend and upper Laguna Madre, allowing southerly plant and animal communities to expand northward and, due to fewer disturbances from frost, mature developing different ecosystems over time (Union of Concerned Scientists 2009). Sea level is projected to rise around 20 cm in the next 50 years (IPCC 1998; 2001). The influx of salt water is most likely to affect species and communities that require brackish to fresh water and these communities are already at risk from many other stressors. In many places, however, the rates of coastal subsidence are several times greater than the rate of sea level rise; that is, the problem of land sinking is greater than the problem of sea rising. Furthermore, according to some scenarios of the IPCC, there would be an important threat posed by climate change to the Laguna Madre, which might contribute to the dispersal of chemical pollutants and exotic species. The hypersaline nature of the Laguna Madre would also be expected to change.

Rio Bravo/Rio Grande

The Rio Grande ranks twentieth in length of the world's rivers and is the fifth longest river in North America at an approximate length of 3,059 km (1,900 miles). The headwaters in the United States are fed from snowmelt in the San Juan Mountains in Southern Colorado, at more than 3.96 km (13,000 feet) above sea level, before entering into New Mexico and flowing towards the border between the United States and Mexico 12 kilometers (7.45 miles) northwest of El Paso. Although hundreds of miles of the Upper Rio Grande cut across New Mexico, much of the southern portion of the Rio Grande, as known in the United States, or the Rio Bravo del Norte, as known in Mexico—approximately two-thirds of the river's total length—serves as an international border between the state of Texas and the northern Mexican states of Chihuahua, Coahuila, Nuevo León, and Tamaulipas, for the 2,053 kilometers (1,275 miles) of river boundary (Tate, 2002; McNeese, 2005; Parcher et al. 2010). The regional watershed of the Rio Grande covers a large portion of the Southwest, a total of nearly 547,000 km^2 (340,000 square miles). Given the region's arid climate, only a little more than half of that area—283,000 km^2 (176,000 square miles)—provides tributary river flows that feed the Rio Grande (McNeese, 2005).

Figure 20. Map of the Rio Grande



Source: <http://earthobservatory.nasa.gov/Features/RioGrande/water_hyacinth_map.php>.

Downstream, several rivers provide tributary waters that feed the Rio Grande (Fig. 21), including Rock Creek, Alamosa Creek, Trinchera Creek, and the Conejos River, all flanking the San Luis Valley in Colorado. In New Mexico, the Puerco, Red, and Chama Rivers add their cold mountain waters to the Rio Grande's flow. Other sources include four great draws—Galisteo Creek, the Jemez River, Rio Puerco, and Rio Salado—that are generally dry except when great rain storms deliver great pours of water into their dusty beds (McNeese 2005).

Figure 21. Binational Waterbodies in the Rio Grande/Bravo Basin

Source: Patiño-Gómez and McKinney, 2006.

The two main tributaries, the Rio Conchos and the Pecos River, revive the surface flow of the Rio Grande-Rio Bravo after the river passes through the Forgotten Reach south of El Paso, Texas. The Rio Conchos (Fig. 22) flows from the Sierra Madre in Mexico contributing about 35 to 40% of the surface flow in the lower basin (Parcher et al. 2010). The Rio Conchos is a vital addition to the flow of the Rio Grande. As the great river crosses desert lands, it would peter out if not for this additional water supply. A second Salado River, this one flowing out of the Coahuila Mountains of northern Mexico, also reaches the Rio Grande. Along the final length of the river, the coastal plain causes the Rio Grande to spread out. As the Rio Grande approaches the Gulf Coast, it moves into a delta region, flowing at a low elevation of approximately 9 m (30 feet) above sea level. This is an extensive delta that spreads out across the southwestern landscape and covers 804,672 km^2 (5,000 square miles), an area almost equally divided between Texas and Mexico. The Rio Grande empties about 914 m^3 (3,000 cubic feet) of water per second into the Gulf of Mexico. Depending on the season, the river may have a faster or slower flow. The peak flow occurs in May or June in the early parts of the river due to melting snow and rain, while the lower parts of the river experience their peak flows in June or July due to summer rains (McNeese 2005).

Figure 22. Rio Grande Watershed

Source: Wong et al. 2007.

The entire Rio Grande-Rio Bravo Basin encompasses 924,300 km^2 (574,330 square miles) of land in the U.S. and Mexico. The contributing watershed is divided almost in half between the two countries, with 231,317 km^2 (143,733 square miles) in Colorado, New Mexico, and Texas and 227,149 km^2 (141,144 square miles) in Chihuahua, Nuevo León, Coahuila, Durango, and Tamaulipas (Parcher et al. 2010).

The collective physical features of an arid climate, with an average rainfall in the basin ranging from 200 to 900 millimeters, an evaporation rate exceeding water gained from precipitation, and a landscape dominated by agriculture with limited surface- and ground- water supplies, present a major challenge to manage this transboundary water resource for a growing population along both sides of the international border (Parcher et al. 2010). The present population along the Rio Grande is estimated in 17,753,370 people (13,392,900 in Mexico and 4,360,470 in the U.S.) (TFDD 2011).

River and Basin Division

The basin is comprised of two sub-basins: the Upper Rio Grande basin (above Ft. Quitman, Texas) includes Colorado, New Mexico, and part of Texas, and the Lower Rio Grande Basin (below Ft. Quitman) includes parts of Chihuahua, Durango, Coahuila, Nuevo Leon, Tamaulipas, and Texas states (Patiño-Gómez and McKinney 2006). Some authors (*e.g.* McNeese 2005) divide the Rio Grande into three parts: the Upper (from San Juan Mountains of southern Colorado to Albuquerque), Middle (from Albuquerque to Truth or Consequences, New Mexico or from Cochiti Dam to Elephant Butte Dam) and Lower Rio Grande (from Elephant Butte to the Gulf Coast). Some others (*e.g.* Parcher et al. 2010) divide the river in five major sections:

1. the Rio Del Norte, from the headwaters to Elephant Butte Reservoir;
2. from Elephant Butte Reservoir to the Rio Conchos;
3. from the Rio Conchos to Amistad Reservoir;
4. from below Amistad Reservoir to Falcon Reservoir;
5. from Falcon Reservoir to the Lower Rio Grande Valley.

Ecoregions and Weather

The Rio Grande flows through seven physiographic provinces including the Southern Rocky Mountains, Colorado Plateau, Basin and Range, Great Plains, Coastal Plain, Sierra Madre Occidental, and Sierra Madre Oriental (Benke and Cushing 2005). Except for the snowmelt at the headwaters in Colorado and the subtropical climate at the mouth near the Gulf of Mexico, most of the river flows through arid regions, including North America's largest desert, the Chihuahuan Desert, as a result the Rio Grande basin lies entirely within the dry domain ecoregion as defined by Bailey (1995). The basin is more than 30% arid and drains an area greater than the size of California (Revenga et al. 1998).

The Rio Grande basin contains six freshwater ecoregions, including the Upper Rio Grande, Lower Rio Grande, Pecos, Rio San Juan, Rio Salado, and Rio Conchos (Benke and Cushings 2005). Most of the Colorado parts of the basin are classified as temperate steppe. Annual rates of precipitation in Colorado are heterogeneous, however; they range from as much as 112 cm (44 inches) in the western alpine areas (mostly as snowfall) to as little as 20 cm (eight inches) in the central portions. These precipitation patterns and ecosystem designations extend into the central portion of the basin in New Mexico. Most of the Rio Grande basin in New Mexico receives less than 36 cm (14 inches) of precipitation annually, and much of the upper basin ranges from tropical-subtropical steppe and mountain to temperate steppe. The central part of the basin within New Mexico is primarily tropical-subtropical mountain surrounded on both sides by tropical-subtropical desert. From El Paso through the Big Bend area, the Rio Grande basin is classified as tropical-subtropical desert except for the extreme eastern edge of the basin, which is tropical-subtropical steppe, this area generally receives less than 36 cm (14 inches) of precipitation annually. Precipitation increases with distance below the Big Bend; much of the lower Rio Grande basin receives 51 cm (20 inches) annually, and the areas nearest the Gulf Coast receive as much as 71 cm (28 inches). The Texas/Mexico border is an arid region, with limited supplies of both surface and groundwater. The lower, narrow portion of the Rio Grande basin extending from Eagle Pass to the Gulf is therefore classified as tropical/subtropical steppe (Schmitt et al. 2004). Along the entire river, water lost through evaporation exceeds water gained from precipitation (Tate 2002).

Biodiversity

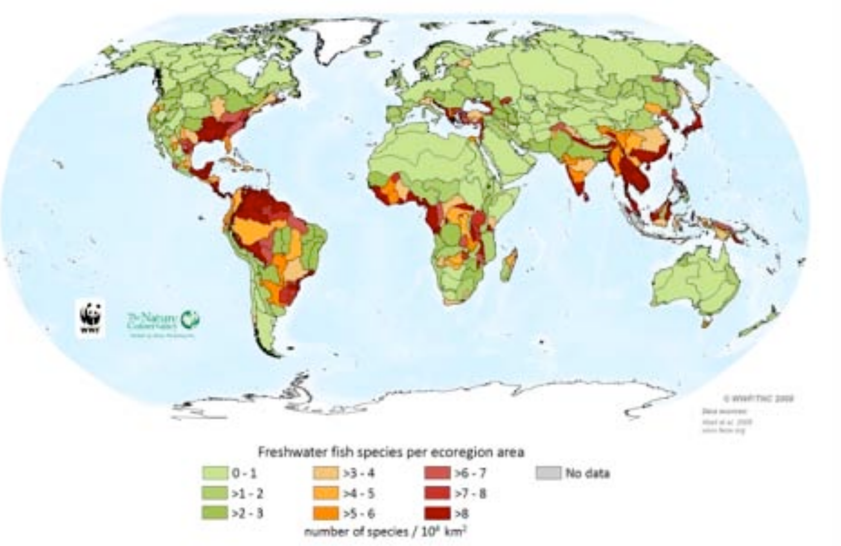
The Rio Grande is considered as a *Globally Outstanding* river for its biological distinctiveness (estimated in function of its Species Richness, Endemism and Ecosystem Diversity) and has the highest priority for conservation as a result of the number of endangered species (Olson et al. 1998; Bezaury Creel at al. 2000). It is also considered a terrestrial and hydrological priority region for Mexico (Arriaga Cabrera et al. 1998).

Benthic diatoms (*Nitzschia, Navicula, Achnanthes, Cocconeis, Fragilaria, Staurosira, Synedra, Amphora, Luticola, Caloneis,* and *Tryblionella),* cyanobacteria *(Oscillatoria, Spirulina, Schizothrix, and Lyngbya),* and green algae *(Cladophora, Closterium, Cosmerium, Pediastrum, and Scenedesmus*) are reported to be common (Benke and Cushing 2005).

Riparian vegetation varies along the length of the Rio Grande. Lowland riparian areas in the upper Rio Grande of Colorado and central and northern New Mexico were historically dominated by cottonwoods, with willows and a variety of native shrubs. Unfortunately, nonnative species increasingly dominate riparian areas in this region. Saltcedar and Russian olive are particularly successful invaders. Nonnative species also play a major role in the riparian zones of southern New Mexico and western Texas. Saltcedar dominates much of the riparian areas until the confluence of the Rio Grande with the Rio Conchos. Dominant riparian tree species in the lower Rio Grande below the confluence of the Rio Conchos include mesquite, hackberry, cedar elm, anacua, black willow, and retama. In the aquatic environment the nonnative macrophytes water hyacinth and hydrilla are dominant. Introduced grasses, such as Guinea grass and buffelgrass, also are becoming dominants in many areas of the riparian zone of the lower Rio Grande (Benke and Cushing, 2005; Contreras Balderas 2008).

The freshwater fauna of the Rio Grande is likely the richest of any arid-region river system in the world (Olson et al. 1998) (Fig. 23). The Rio Grande once had a much larger group of freshwater mussels (*Unionidae*) than are presently found. At least 16 species of unionid mussels once occurred within the Rio Grande drainage, but these are among the fastest declining groups in the basin, in part because of their environmental sensitivity and intolerance to degraded conditions. Some mollusks are expanding in the basin, such as the introduced and highly tolerant Asiatic clam (*Corbicula fluminea*), which are found to be locally abundant at sites throughout the Rio Grande. Other common bivalves in the lower Rio Grande of Texas include paper pond-shell, tampico pearly mussel, and yellow sandshell mussel (Benke and Cushing 2005; Winemiller et al. 2010).

Figure 23. Freshwater Fish Species/Ecoregion Area



Note: Species richness adjusted for ecoregion size.
Source: FEOW.

Some crustaceans such as *Macrobrachium acanthurus, Palaemonetes kadiakensis* and *Procambarus simulans regiomontanus* are characteristic of the river (Conabio 2011).

Approximately 166 species of fishes have been found in the Rio Grande when both freshwater (86) and brackish water (80) species are considered (Benke and Cushing 2005). The fish fauna of the lower Rio Grande contain nearly twice as many species as the Rio Conchos and three times as many species as the upper Rio Grande. The fishes of the Rio Grande basin are dominated by a rich minnow (*Cyprinidae*) assemblage. Where spring systems exist, unique components of pupfishes and livebearers are found. Species that are found within the larger basin include the Conchos pupfish (*Cyprinodon eximius*), Mexican stoneroller (*Campostoma ornatum*), ornate shiner (*Codoma ornata*), Rio Grande chub (*Gila pandora*), Tamaulipas shiner (*Notropis braytoni*), Chihuahua shiner (*N. chihuahua*), and Rio Grande shiner (*N. jemezanus*).

Species endemic to the Rio Grande include the Devil's River minnow (*Dionda diaboli*), Big Bend gambusia (*Gambusia gaigei*), and spotfin gambusia (*Gambusia krumholzi*). Near-endemics include the Rio Grande silvery minnow (*Hybognathus amarus*), phantom shiner (*Notropis orca*), and bluntnose shiner (*N. simus*) (Contreras-Balderas 2008).

At least 34 species are considered rare or endangered and many appear on the endangered species list of the United States. Endangered species include shovelnose sturgeon, American eel, a number of minnows (Mexican stoneroller, Maravillas red shiner, proserpine shiner, manatial roundnose minnow, Devils River minnow, Rio Grande chub, Chihuahua chub, Rio Grande silvery minnow, Chihuahua shiner, Rio Grande shiner, Pecos bluntnose shiner, Tamaulipas shiner, ornate shiner), two suckers (west Mexican redhorse, blue sucker), three catfishes (headwater catfish, Chihuahua catfish, and a unique form of blue catfish in the Rio Grande in west Texas), a trout (Rio Grande cutthroat trout), and four pupfish (Leon Springs pupfish, Comanche Springs pupfish, Pecos pupfish, Conchos pupfish). In addition, there are four livebearers (Big Bend gambusia, blotched gambusia, Pecos gambusia, and an undescribed species of gambusia from the Del Rio area), a darter (Rio Grande darter), and a number of coastal forms (opossum pipefish, snook, fat snook, river goby). Some fish species such as the roundnose minnow (*Dionda episcopa*) and the Rio Grande shiner (*Notropis jemezanus*) are also listed in the Official Mexican Norm for Species at Risk (Contreras-Balderas 2008). The Rio Grande is also home to endangered silvery minnows where is found the last remnant of their historical habitat (Hurd and Coonrod 2007). Several species of fishes have gone extinct in the basin, including phantom shiner, bluntnose shiner, Amistad gambusia, and very likely blackfin goby (Benke and Cushing 2005).

The Lower Valley serves as a temporary or permanent home for hundreds of bird species (Tate, 2002). The Rio Grande delta is considered a priority site for migratory aquatic birds conservation in Mexico (Bezaury Creel at al. 2000). Many bird species in the basin, such as the common yellow-throat, great blue heron, snowy egret, black-crowned night heron, white-faced ibis, belted kingfisher, and green kingfisher, are dependent on the Rio Grande (Benke and Cushing 2005). Nearly half of all birds whose habitat is deciduous vegetation near water will inhabit these areas. The U.S. federal list of endangered species includes six birds in the Rio Grande basin, half of them migratory songbirds, half are large birds of prey (Bilbe 2006).

Aquatic reptiles and amphibians of the Rio Grande include the plainbelly water snake, bullfrog, Rio Grande leopard frog, snapping turtle, box turtle, and western ribbon snake. The American alligator occurs in the Coastal Plain of the Rio Grande (Benke and Cushing 2005). The seaward boundary of the Laguna Madre is formed by Padre Island, the northern part of which comprises the Padre Island National Seashore (U.S. National Park Service), a nationally significant recreational and wildlife area that includes nesting habitat for the endangered Kemp's ridely sea turtle (Lepidochelys kempii) and other species of wildlife. Additional recreational and wildlife areas managed by the states are situated along the Rio Grande and its tributaries and impoundments; these are also important to migratory species (Schmitt et al. 2004).

Beaver, mink, and nutria are also found in the river (Benke and Cushing 2005).

Impacts

Major structural impoundments, increased population growth, and over allocation of water for agricultural and industrial development in the Rio Grande watershed have drastically changed this transboundary river (Parcher et al. 2010). Heavy and increasing demands are placed on Rio Grande waters to meet growing water supply and waste disposal needs of population centers in the U.S. and Mexico, which have also affected water and habitat quality (Schmitt et al. 2004). Public interest groups and community leaders in the US:Mexico border region have become increasingly concerned about the quality of the once mighty Rio Grande. Border residents have expressed great concern about potential contamination of the river and its tributaries from the discharge of untreated municipal sewage, industrial wastewater and urban and agricultural run-off. At present, pollution of different sorts encompasses issues of particular concern, including:

1. contaminants in ground water, surface water, and biota from agricultural, municipal, and industrial activities;
2. airborne pollutants from fossil-fuel combustion and other activities;
3. contaminants from past and present mining activities and mineral deposits, and
4. pathogens, pharmaceuticals, hormones, and other contaminants released in treated and untreated human and animal wastewaters (Buckler and Strom 2004).

Chemical Pollution

Since 1950, agricultural chemicals and petrochemicals have had an increasing impact in the lower Rio Grande region. At the present time, a number of chemicals can be found in the basin throughout the lower stretches of the river in quantities approaching or exceeding the guidelines of the United States Environmental Protection Agency for the safety of fishes and other aquatic organisms (Edwards and Contreras-Balderas 1991).

The governments of Mexico and the United States performed a joint study on toxic substances in the Rio Grande from 1992 until 1994 in a major binational cooperation in scientific investigation into common environmental concerns. The results of the study were released to the public in September 1995. The study was prompted by a widely held public concern that the river was being contaminated by toxic substances, possibly from industrial and agricultural sources near the border. The concern with industrial sources was intensified by the large increase in the number of industrial plants in recent years. There are currently over 1,400 such plants in the border region.

Thirty chemicals that exceeded screening levels were considered to be of potential concern, and were assigned an approximate level of importance based on occurrence. A high-priority group included residual chlorine, methylene chloride, toluene, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, zinc, chlordane, p,p'-DDE, dieldrin, gamma-BHC (lindane), total PCBs, and cyanide. A medium-priority group consisted of non-ionized ammonia, para-chloro-meta cresol, phenol, and diazinon. A low priority group was composed of phenolics recoverable, chloroform, antimony, thallium, bis (2-ethylhexyl) phthalate, diethyl phthalate, and di-n-butyl phthalate.

Based on this analysis, it was concluded that several places exhibited either high potential or slight to moderate potential for toxic chemical impacts. At least some toxics exceeded the screening levels' in one of the various media tested (water, fish tissue or sediment) at every mainstem and tributary station tested. Of the 25 mainstem and large tributary locations sampled for fish, carp with one or more toxic chemicals exceeding fish tissue screening criteria were detected at 23 (or 92%) of the stations. The results of the Rio Grande Toxics Study also indicate that heavy metals frequently exceeded the screening criteria for water quality, sediment quality or for fish tissue. Phthalates and methylene chloride (carcinogens) were detected in water in excess of screening levels at different test stations. Several other frequently used industrial chemicals, including, toluene, benzene, tetrachloroethylene, and xylene (carcinogens too) were detected at one or more sites in the water, although not at levels in excess of screening criteria. Sediment samples of different stations resulted in variable levels of mortality for fathead minnow (Pimephales promelas), ranging from 25 to 100%. Polychlorinated biphenyls (PCBs) were found in fish tissue at levels exceeding screening criteria at 5 sites. Also five stations showed the pesticide DDT in excess of screening criteria (Kelly and Contreras-Balderas 1994).

Mainstem Sites

High Potential for Toxic Chemical Impacts:

- Downstream from El Paso–Ciudad Juárez
  Downstream from Laredo–Nuevo Laredo

Slight to Moderate Potential for Toxic Chemical Impacts:

- Upstream from Rio Conchos confluence near Presidio/Ojinaga
- Downstream from Eagle Pass/Piedras Negras
- Downstream from Anzalduas Dam
- Below Anhelo Drain South of Las Milpas

Tributaries

High Potential for Toxic Chemical Impacts:

- El Paso Public Service Board Haskell R. Street Wastewater Treatment Plant
- Ciudad Juárez Discharge Canal
- Manadas Creek
- Zacate Creek
- Arroyo El Coyote
- Anhelo Drain

Slight to Moderate Potential for Toxic Chemical Impacts:

- Rio Conchos
- San Felipe Creek
- Unnamed Tributary South of Eagle Pass–Piedras Negras
- Arroyo Los Olmos (TCEQ 2010).

In another study Levings et al (1998) reported that pesticides were detected in both agricultural and urban land-use areas, with 29 percent of shallow wells containing at least one pesticide. Prometon and metolachlor were the most frequently detected, yet neither compound exceeded EPA drinking-water standards. Also Radon, a naturally occurring radionuclide in the Rio Grande Valley, was detected in all ground-water samples in concentrations that ranged from 190 to 2,300 picocuries per liter. About 57 percent of the samples exceeded 300 picocuries per liter, the proposed EPA drinking-water standard. The presence of DDT and its metabolites, DDE and DDD, in bed sediment and whole-body fish confirmed the persistence of this pesticide in the environment. Recently, Hinck et al (2009) conclude that the remaining DDT concentrations in different parts of the Rio Grande represent a greater risk to bald eagle. Cis-chlordane, trans-chlordane, and trans-nonachlor were also detected in whole-body fish samples. Highly elevated concentrations of antimony, arsenic, cadmium, copper, lead, mercury, silver, and zinc were detected in bed sediments and elevated concentrations of arsenic, cadmium, copper, lead, and zinc were detected in fish tissue (liver).

Schmitt et al. (2004) after analyzing 368 fish of seven species from 10 sites in the Rio Grande basin determined that overall, fish from stations in the lower Rio Grande basin contained greater concentrations of some contaminants and appeared to be less healthy than those from sites in the central and upper parts of the basin, as indicated by general gradient of pesticide concentrations and biomarker responses from upstream to downstream. In the upper Rio Grande basin, a minimal number of altered biomarkers and few or no elevated contaminant concentrations were noted. The exception was elevated concentrations of total mercury (Hg) in predatory species from Rio Grande at Elephant Butte Reservoir.

Moreover, in the lower Rio Grande basin, organochlorine pesticide residues (DDT metabolites, chlordane-related compounds, dieldrin, and toxaphene) were evident in fish from most sites, and concentrations exceeded toxicity thresholds for fish and wildlife at Rio Grande at Mission, TX, Arroyo Colorado at Harlingen, TX, and Rio Grande at Brownsville, TX. Arsenic concentrations were also comparatively high in bass from Rio Grande at Brownsville, TX. Channel catfish (*Ictalurus punctatus*) from Arroyo Colorado at Harlingen, TX contained especially high concentrations of p,p'-DDE, chlordane-related residues, toxaphene, and dieldrin. In addition to Ethoxyresorufin-O-deethylase (EROD)[8], slightly elevated HAI (Health Assessment Index) scores characterized carp from Arroyo Colorado at Harlingen, TX and a comparatively high frequency of external lesions was noted on bass at Rio Grande at Brownsville, TX. Histopathological examination revealed that the latter were parasite-induced. Comparatively high individual HAI values were noted in the Rio Grande at Brownsville, TX and Falcon International Reservoir, and one or more macrophage aggregate parameters were elevated in carp, bass, or both in the lower Rio Grande. Reproductive biomarkers were also consistent with chronic contaminant exposure in the lower Rio Grande basin sites. Relatively high proportions of intersex largemouth bass were observed at three sites in the lower Rio Grande Basin including Rio Grande at Brownsville, Texas (50 percent),

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[8] A biomarker of exposure to certain planar halogenated and polycyclic aromatic hydrocarbons (PHHs and PAHs) and other structurally similar compounds (Whyte et al. 2000).

RioGrande at Falcon Dam, Texas (44 percent), and Rio Grande at Mission, Texas (20 percent) (Hinck 2009). Relatively low gonadosomatic index scores, and elevated vitellogenin[9] concentrations in male fish were also noted, and large percentages of atretic eggs were observed in the ovaries of female carp from Rio Grande at Brownsville, TX. Although there are other causes for many of the conditions noted, the biomarker data for the lower Rio Grande basin stations are nevertheless consistent with subtle responses to contaminants, an interpretation supported by the chemical data of other recent investigations.

Many of the refuges associated with the Rio Grande and its major tributaries, managed by the USFWS, were identified as being at risk of injury from pesticides, selenium (Se), salt seepage, and other contaminants emanating from agriculture and oil and gas production. These include Alamosa and Monte Vista National Wildlife Refuges (NWRs) in Colorado; Bosque del Apache, Sevellita, Las Vegas, and Bitter Lake NWRs in New Mexico; and Lower Rio Grande Valley, Santa Ana, and Laguna Atascosa NWRs in Texas.

Laguna Atascosa NWR is situated on the landward side of the Laguna Madre at the confluence of the Arroyo Colorado (Fig. 24). The Arroyo Colorado, which flows through and supplies fresh water to the refuge, is heavily contaminated by agricultural chemicals and is the primary reason that Laguna Atascosa is among the Rio Grande Basin refuges identified as being at risk due to contaminants. The Mercedes Unit of Rio Grande Valley NWR, along with state and private refuges, are situated on the north shore of the Arroyo Colorado at Llano Grande Lake, upstream of Harlingen, Texas. Llano Grande Lake has a long history of contamination by organochlorine pesticides and it remains under a fish consumption advisory (Schmitt 2004).

Microorganisms

Despite its critical role in agriculture and potable water supply for the region, few studies have evaluated the microbial quality of the Rio Grande River especially for the parasite *Cryptosporidium*, which causes diarrheal illness and has been responsible for numerous waterborne and foodborne disease outbreaks. *Cryptosporidiosis* may be fatal in people with weakened immune systems and there is currently no effective treatment for the disease. Results of one of these studies showed that the limits of detection of *Cryptosporidium* in the water samples ranged between 20 and 200 oocysts/100 L, equivalent to one or two orders of magnitude than the U.S. EPA annual acceptable risk level of 10-4. Domestic and wild animals such as ruminants, cervids, swine, cats, dogs and other mammals are major sources

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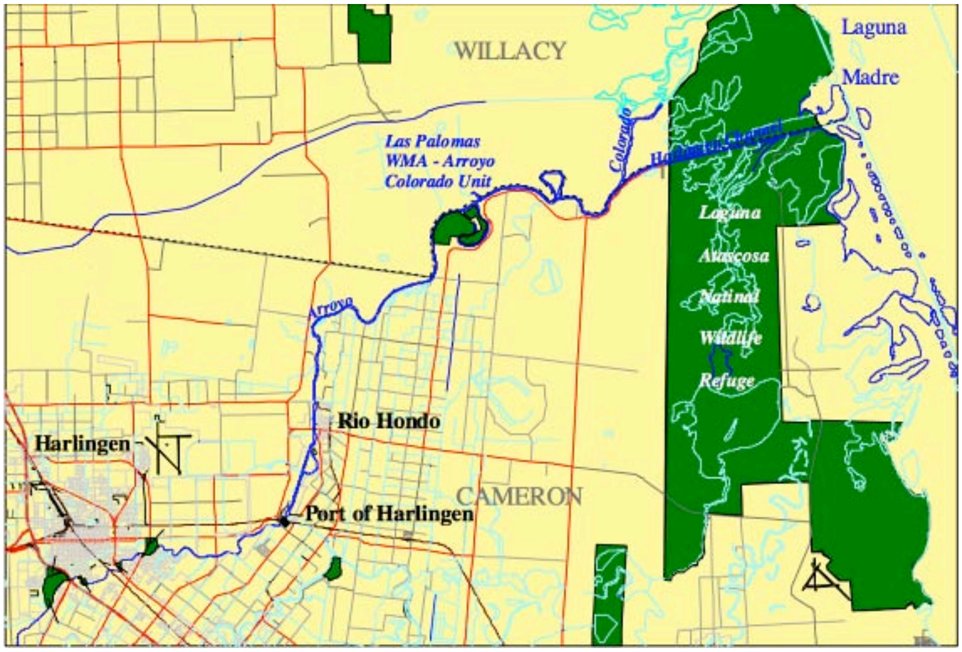
[9] A protein normally found only in females that serves as yolk precursor.

of *Cryptosporidium* oocysts in the environment. Expanded populations of these host animals in an ecosystem result in widespread occurrence of *Cryptosporidium* oocysts in environmental waters (rivers and lakes). Cattle farming and ranching is the most prevalent activity in the Rio Grande watershed, which can contribute to the microbial burden of Rio Grande water. Total and fecal coliform bacteria data showed the significance of animal farming and raw sewage as sources of fecal pollution (Ryu et al. 2005). Other studies have shown great variability in the number of fecal coliforms, and Escherichia coli on a month-to month basis, but have confirmed the consistent presence of Helicobacter pylori along a 112-km segment of the Rio Grande from Sunland Park, NM to Fort Hancock, TX (Mendoza et al. 2004). In relation to this, Parsons Water & Infrastructure Inc. (2005) reported that the overall top *E. coli* contributors were wildlife (primarily avian) at 46 percent and pets at 24 percent. These two groups account for 70 percent of the *E. coli* detected in all the water samples. Humans and livestock contributed 16 and 14 percent, respectively.

Figure 24. Location of Arroyo Colorado



Location of Arroyo Colorado just upstream of Port of Harlingen to its confluence with Laguna Madre in Willacy/Cameron Counties.

Source: El-Hage and Moulton 2000.

Invasive Species (Biological Pollution)

Another complicating factor is that the Rio Grande has several non-native and/or "introduced" species. These come from at least two sources: fisheries in reservoirs such as *La Amistad*, *Falcon* and others, and the invasion of saltwater-tolerant species as waters become more saline due to reduced freshwater flows or other factors (Kelly and Contreras-Balderas 1994).

Similar findings were reported by Levings et al (1998), who suggest that one of the main pathways was fish stocking which has probably resulted in the displacement of native species through competition or predation. They also attribute the success of invaders to the fact that most of these species were omnivorous and pollution-tolerant. The higher resistance to environmental stressors and better adaptation to adverse conditions of invasive fish in aquatic desert environments has been already demonstrated (Castelberry and Chech 1986).

Table 1 shows the results of non native species found in the Binational Study Regarding the Presence of Toxic Substances in the Rio Grande/ Rio Bravo and its Tributaries Along the Boundary Portion Between the United States and Mexico. In this study, apparently there was a low collection efficiency, which appears to have missed primarily euryhaline species (Kelly and Contreras-Balderas 1994).

Table 1. Status and Preferred Habitat of Fish Species Collected in the Rio Grande and Tributaries

Scientific Name	**Common Name**	**Status**	**Preferred Habitat**
Cyprinella venusta	Blacktail shiner	I	F
Cyprinus carpio	Common carp	I	F
Fundulus zebrinus	Plains killifish	I	F
Morone chrysops	White bass	I	F
Lepomis auritus	Redbreast sunfish	I	F
Lepomis microlophus	Redear sunfish	I	F
Micropterus dolomieu	Smallmouth bass	I	F
Sizostedion vitreum	Walleye	I	F
Tilapia aurea	Blue tilapia	I	F

Status: N = Native, I = Introduced.
Preferred habitat: F = Freshwater, B = Brackish water, M = Marine.
Source: CILA, 1994.

Collections of fishes from the lower Rio Grande during the past 138 years suggest two indigenous faunal assemblages. One fauna is upstream, composed of mostly of freshwater species, and the other is a downstream assemblage composed of a mixture of the more abundant upstream elements and more estuarine species.

However collections in the early 90s in the lower Rio Grande made by Edwards and Contreras-Balderas (1991) indicate that major alterations in these fish communities have occurred. The upstream fauna has lost many of its characteristic freshwater components; exotic or estuarine forms have replaced native freshwater species. The downstream fauna has fewer freshwater taxa with replacement by estuarine and marine species. The authors report 20 estuarine and 59 marine species for the lower Rio Grande. They also observed a general decline (or disappearance) of some species throughout the lower Rio Grande.

A perfect separation of native and introduced species is not possible, given that fishes such as American eel (*Anguilla rostrata*), freshwater mullet (*Agonostomus monticola*) and freshwater goby (*Awaous banana*) are standard members of the deltaic native freshwater community, often penetrating long distances inland, although they represent forms also occurring in marine habitats (Contreras-Balderas et al. 2002). These authors found a decline in primary fishes, mostly Nearctic; invading peripheral colonizers (mostly marine) penetrating farther upstream through time with a change of lower to higher salinity fishes; secondary forms changing irregularly although also slowly descending, especially near the delta; and an increasing number of introduced invasives in the reservoirs (Table 2). However, freshwater forms were also suffering declines near the delta, especially in more recent times. An interesting aspect is that the fish community size, even under altered conditions seems to remain stable, except that the natives have been replaced by colonizers.

Invasive aquatic plants also constitute a serious problem in the Rio Grande. Invasive plants squander large amounts of water all across the Rio Grande and upset the ecosystem. The unchecked growth of salt cedar, giant salvinia, water hyacinth, hydrilla and Eurasian watermilfoil, impacts water supply, water quality, hydropower production, flood control, navigation, recreation, fish and wildlife, property values, and in rare cases, loss of human life. The economic growth of the Rio Grande basin depends on water, so controlling, and ultimately stopping, the spread of invasive aquatic species is of paramount concern. Already strained by population growth and agricultural needs, the Upper Rio Grande, from El Paso to the Big Bend, is being sucked dry by salt cedar (*Tamarix spp*). The Middle Rio Grande, from Del Rio to Zapata, suffers from exotic *Arundo donax* giant cane ("Carrizo cane"), and Eurasian Water Milfoil (*Myriophyllum spicatum*). The Lower Rio Grande, from Lake Amistad to the Gulf of Mexico, has been invaded by hydrilla (*Hydrilla verticillata*) and water hyacinth (*Eichhornia crassipes*)(TWCA 2010)

Table 2. Exotic Species Reported by Edwards y Contreras Balderas 1991

Scientific Name	**Common Name**	**Status**	**Preferred Habitat**
Cyprinus carpio	Common carp	I	F
Carassius auratus	Goldfish	I	F
Notemigonus crysoleucas	Golden shiner	I	F
Morone chrysops	White bass	I	F
Lepomis auritus	Redbreast sunfish	I	F
Lepomis gulosus	Warmouth	I	F
Lepomis microlophus	Redear sunfish	I	F
L. microlophus X L. macrochirus	Sunfish hybrid	I	F
Pomoxis annularis	White crappie	I	F
Oreochromis aureus	Blue tilapia	I	F

Status: N = Native, I = Introduced.
Preferred habitat: F = Freshwater, B = Brackish water, M = Marine.

Source: IBWC, 1994.

In particular, the hyacinths and hydrilla have been taking over large sections of the river. Not only do they draw water up in their roots and transpire it into the atmosphere, but these invader species also clog the free flow of the river (Fig. 25). The plants have some of the highest growth rates in the world and can double their population reaching biomass densities as high as 200 tons per acre in less than two weeks. In recent years, the Rio Grande Watermaster had to release 20 to 25 percent more water from Falcon Reservoir to push irrigation water past blockages in the middle of the river (Fig. 26).

Exotic plant infestations can alter the environment detrimentally by replacing native aquatic vegetation and affecting fish populations, also prevent sunlight and oxygen from getting into the water. Decaying plant matter reduces dissolved oxygen content of the water, which has potentially lethal ramifications for aquatic life. They impair water quality, impede water flow and reduce biological diversity (Allen 2002). By restricting flow, they can artificially raise water levels and cause increased water loss through bank absorption (Everitt et al. 2003).

Figure 25. Rio Grande Upstream from Brownsville, Texas

Picture of the Rio Grande upstream from Brownsville, Texas, near Lloyd Bend, taken on August 26, 2001. The water hyacinths have completely covered the river making it essentially impassible.

Source: http://earthobservatory.nasa.gov/Features/RioGrande.php).

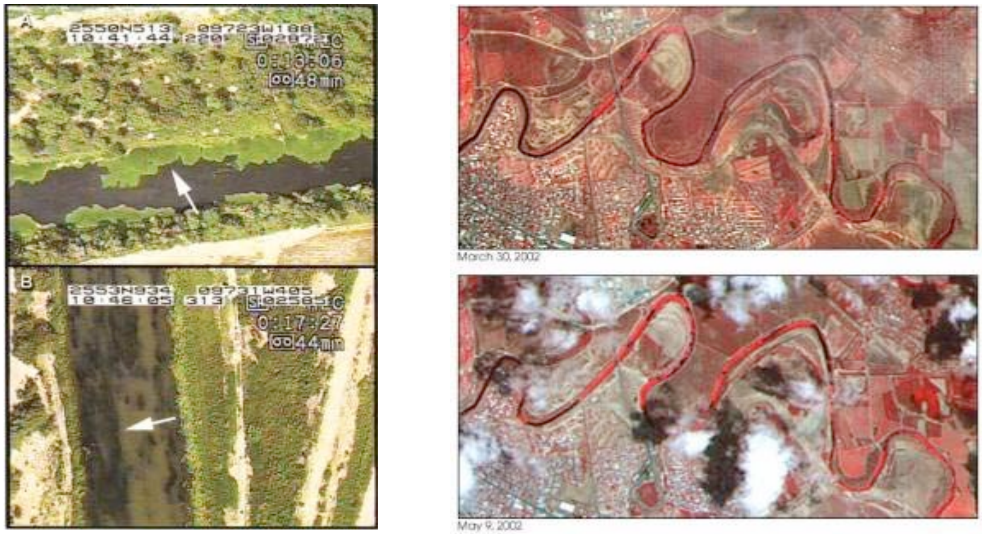
Just as the plants can clog the river, they can clog up water distribution pipelines and aqueducts. Brownsville, Texas, erected fences and gates to keep the vegetation from being washed into the city's water. But these structures have been overwhelmed, and so much vegetation has piled up around the water intake pumps that some fencing has collapsed from the pressure. The city has sent workers to stand in the river with poles and force floating platforms of plants away from the water intakes while other workers repair the fences and eradicate the infestations (Allen 2002).

A sort of vicious circle seems to exist, as the hyacinths reduce the river flow, but the reduced flow of the river also led to the formation of masses of hyacinth, (Parcher et al. 2010). As a control measure in December 2006, 20,000 grass carp were released in the Rio Grande below Falcon Dam with the intention to reduce hydrilla populations (IBWC 2006).

Impoundments

From headwaters to the Gulf of Mexico, the Rio Grande has been transformed by human attempts to adapt to its variability. One example is the complex network of flow-control structures that has been constructed on the Rio Grande and many of its tributaries to provide water storage and flood/sediment control and to meet inter- state and international water delivery obligations (Tate 2002). Currently, there are 100 large dams[10], eight of which are on the main stem of the river, and there are six very large dams[11] (Wong et al. 2007).

Figure 26. Infestations of Waterhyacinth and Hydrilla in the Rio Grande Near Brownsville, Texas



Left: Aerial normal color video images of infestations of waterhyacinth (A) and hydrilla (B) in the Rio Grande near Brownsville, Texas. The arrows point to water hyacinth and hydrilla in each respective image. The imagery was obtained on 19 September 2002 at an altitude above ground level of approximately 600 m

Source: Everitt et al., 2003.

Right: In the near-infrared region of the spectrum, photosynthetically active vegetation is highly reflective. Consequently, vegetation appears bright to the near infrared sensors aboard ASTER, and water, which absorbs near infrared radiation, appears dark. In these false-color images produced from the sensor data, healthy vegetation is shown as bright red while water is blue or black. Notice a water hyacinth infestation is already apparent on March 30 near the center of the image. By May 9 the hyacinth population has exploded to cover over half the river in the scene.

Source: <http://earthobservatory.nasa.gov/Features/RioGrande.php>.

The following description of the impoundments controlling the flow of the Rio Grande was provided by Schmitt et al. (2004). Cochiti Reservoir, located roughly 50 mi (80 km) north of Albuquerque, New Mexico is the northernmost major impoundment on the Rio Grande mainstem (Fig. 27). Below Cochiti Reservoir, the Angostura Dam diverts water to supply parts of the Middle Rio Grande Conservancy District. Waters from the Jemez Canyon Reservoir enter the Rio Grande below Angostura Dam, upstream of Albuquerque. Below Albuquerque, water is diverted again at the Isleta Diversion Dam. To reduce excessive evaporative losses below San Acacia, New Mexico, a 113-km (70-miles) canal known as the Low Flow Conveyance Channel (LFCC) was constructed parallel to the Rio Grande in the 1950s; however, subsequent sedimentation of the structure

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[10] Higher than 15 m.

[11] Higher than 150 m.

necessitated its closure as a conveyance. Currently, the LFCC collects agricultural return flows from irrigated areas near the river and provides water to the Bosque del Apache National Wildlife Refuge. Downstream of the refuge, the entire flow of the Rio Grande is captured by Elephant Butte Reservoir (U.S. Bureau of Reclamation - USBR), then again by Caballo Reservoir (USBR). Exiting Caballo Reservoir, the Rio Grande flows southwesterly along the western edge of Las Cruces, New Mexico and enters Texas northwest of El Paso. Above El Paso, at the American Dam (USBR), nearly all the remaining water is diverted into the American Canal (U.S.) and the Acequia Madre (Mexico) for agricultural and municipal uses.

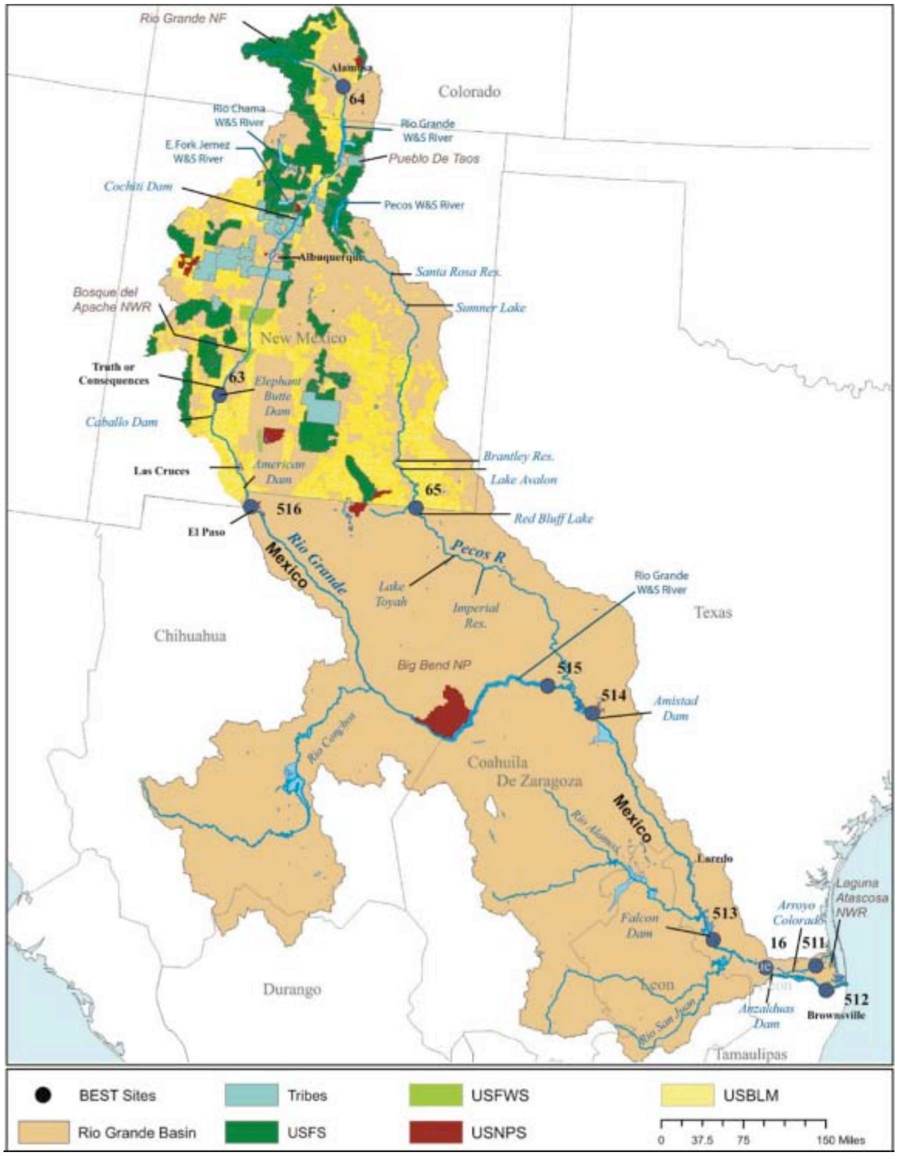
The waters of the Rio Grande and its hydrologic infrastructure downstream of Fort Quitman, Texas (east of El Paso) are managed by the International Boundary and Water Commission (IBWC) of the U.S. Department of State according to the terms of several treaties with Mexico. For about 402 km (250 miles) below El Paso to the confluence of the Rio Conchos near Presidio, Texas, flows in the Rio Grande are intermittent and comprise storm runoff, irrigation return waters, and municipal waste. From Presidio downstream to Amistad International Reservoir and the confluence of the Pecos River most of the water in the Rio Grande originates in Mexico and is contributed by the Rio Conchos.

The Pecos River originates in the Sangre de Cristo Mountains east of Santa Fe, New Mexico and flows some 1,480 km (926 mi) southward and eastward across New Mexico and Texas to its confluence with the Rio Grande near Langtry, Texas near the upstream end of Amistad International Reservoir. The Pecos River drains some 99,228 km^2 (38,300 mi^2). Over its length the Pecos River is controlled by a series of impoundments and other water management structures from which water is diverted for agriculture and other uses. Impoundments on the Pecos River in New Mexico include Brantley Reservoir (formerly Lake McMillan), Lake Sumner (formerly Alamogordo Reservoir), Santa Rosa Lake, and Avalon Lake. Impoundments in the Pecos River Basin in Texas include Red Bluff Lake, Lake Toyah, and Imperial Reservoir.

Upstream of Del Rio/Ciudad Acuña the waters of the Rio Grande, along with those of the Pecos and Devil's Rivers, are impounded by Amistad International Reservoir. Below Amistad Dam the river is free-flowing for 440 km (273 mi) until it is again impounded in Falcon International Reservoir. From Falcon Dam to the Gulf of Mexico, a distance of 480 km (298 mi), the Rio Grande is again generally free-flowing; however, much of the flow is diverted into the Arroyo Colorad at the Anzalduas Dam, north of Hidalgo, Texas. The Arroyo Colorado, a distributary, is managed for flood control via a series of floodways as well as for irrigation. It ultimately flows through the

Laguna Atascosa NWR and then into the Lower Laguna Madre. The remainder of the Rio Grande continues southeasterly, passing through the outskirts of Brownsville, Texas before discharging into the Gulf of Mexico.

Figure 27. Map of the Rio Grande Basin Illustrating Waterways and Impoundments, Federal and Native American Lands and Facilities, Major Metropolitan Areas and State Boundaries

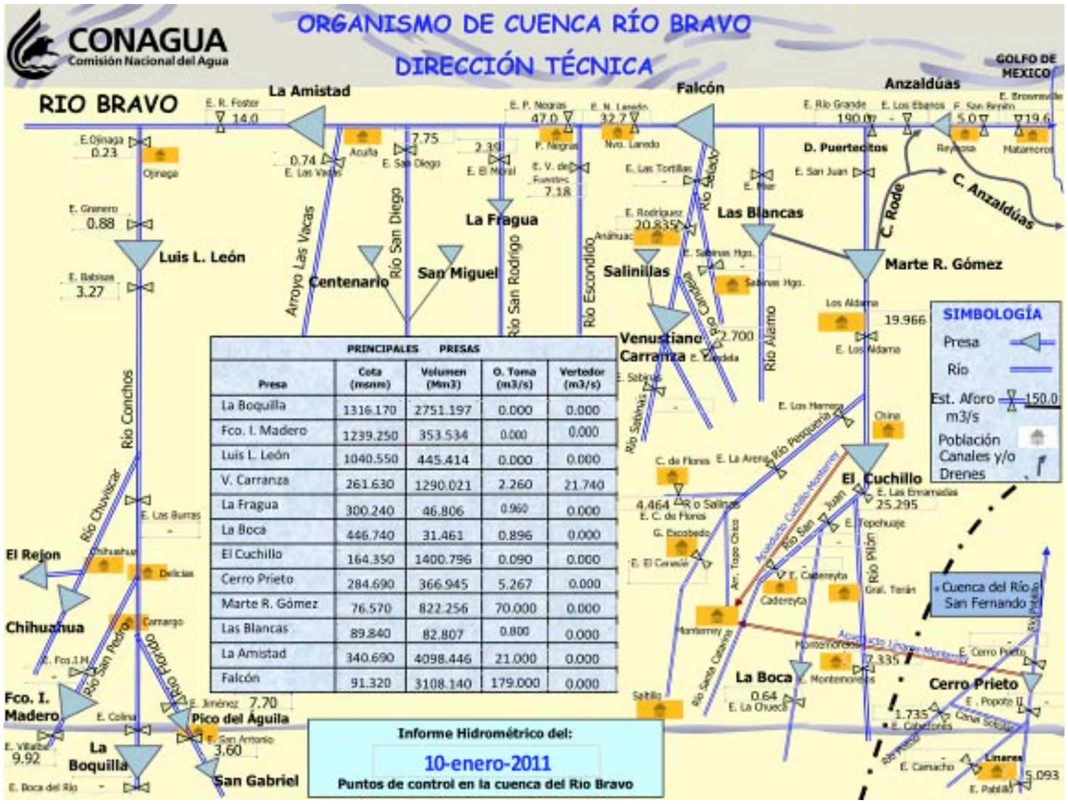


Shown are Native American Tribal lands (Tribes) and lands managed by the U.S. Forest Service (USFS), Fish and Wildlife Service (USFWS), National Park Service (USNPS), and Bureau of Land Management (USBLM).

Source: Schmitt et al., 2004

Water resources development has also been extensive in Mexico, and additional projects are being planned. In addition to Amistad and Falcon International Reservoirs, there are currently 13 storage reservoirs on Rio Grande tributaries in Mexico (Fig. 28). Of these, seven [San Gabriel, Boquilla, F.I. Madero, Pico Del Aguila, Chihuahua, El Rejón, and El Granero (Luis León)] are in the Rio Conchos basin; two are in each of the Rio San Diego (Centenario and San Miguel) and Rio San Juan (El Cuchillo and Marte R. Gómez) basins; and there is one in each of the Rio San Rodrigo (La Fragua) and Rio Salado (Venustiano Arranza) basins (Conagua 2011).

Figure 28. Reservoirs along the Rio Grande in Mexico



PRINCIPALES PRESAS				
Presa	Cota (msnm)	Volumen (Mm3)	O. Toma (m3/s)	Vertedor (m3/s)
La Boquilla	1316.170	2751.197	0.000	0.000
Fco. I. Madero	1239.250	353.534	0.000	0.000
Luis L. León	1040.550	445.414	0.000	0.000
V. Carranza	261.630	1290.021	2.260	21.740
La Fragua	300.240	46.806	0.960	0.000
La Boca	446.740	31.461	0.896	0.000
El Cuchillo	164.350	1400.796	0.090	0.000
Cerro Prieto	284.690	366.945	5.267	0.000
Marte R. Gómez	76.570	822.256	70.000	0.000
Las Blancas	89.840	82.807	0.800	0.000
La Amistad	340.690	4098.446	21.000	0.000
Falcón	91.320	3108.140	179.000	0.000

Informe Hidrométrico del:
10-enero-2011
Puntos de control en la cuenca del Rio Bravo

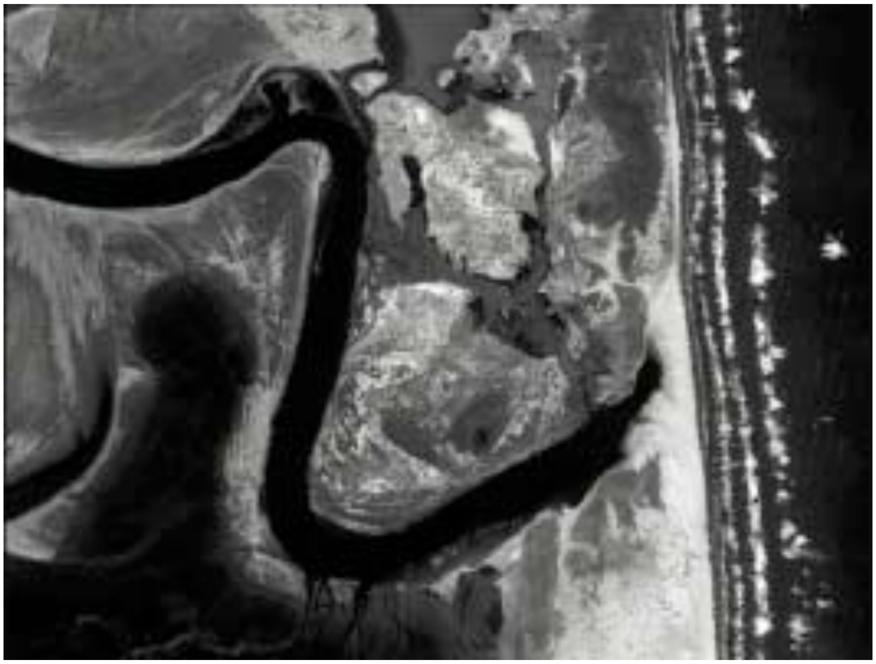
Source: Conagua, 2011.

The Rio Grande River is no longer a natural flowing river. With all of the dams and diversion networks, water is controlled sufficiently. Before water even reaches El Paso, Texas so much of it has been diverted that much of the riverbeds lay dry. These deviations are greatly compounded during drought conditions. The anthropogenic changes in streamflow, such as reservoir impoundments, affect the seasonal timing and magnitude of peak flows and can drastically alter the stream channel and riparian vegetation (Baldwin 2002). Present evidence indicates that the disruption in the normal flood-pulse cycle of the lower Rio Grande, resulting from impoundment of Falcon Lake and poor management of releases from Falcon Lake Dam, have contributed substantially to decline in ecosystem integrity (Small et al. 2009).

In almost every continent, river modification has affected the natural flow of the rivers to a point where, during the dry season, the outflow to the sea is nonexistent (Revenga et al. 2008). The Rio Grande was not the exception, in 2002, the reduction of flow resulted in the mouth of the river being blocked by a sand bar deposition, resulting in closure of flow to the Gulf of Mexico (Parcher et al. 2010) (Fig. 29). The blockage of the mouth of the Rio Grande with silt and sand decreased salinity levels in the lower stretch of the river and subsequently allowed waterhyacinth and hydrilla to move further down stream. Blockage of the mouth of the river was primarily due to reduced stream flow of the Rio Grande attributed to the long-term drought (Everitt et al. 2003).

A positive aspect was that the closing of the mouth has temporarily prevented the invasion of marine species into the lower watercourse.

Figure 29. Sandbar Sedimentation in the Mouth of Rio Grande



A high resolution SPOT satellite image taken May 2, 2002, showing the sandbar sedimentation blocking the flow of the Rio Grande-Rio Bravo into the Gulf of Mexico.

Source: Parcher et al., 2010.

Structural modifications, such as dams, flood control, and channelization, change the dynamics of aquatic ecosystems, fragment existing systems, and join previously unconnected ones. In many cases these structural modifications have made agriculture and transportation possible and therefore have played a key role in global food security. However, altering the structure of a river can also bring about costly changes, such as declines in fish catches, loss of freshwater biodiversity, increases in the frequency and severity of floods, loss of soil nutrients in the flood plain, and increases in the incidence of diseases like schistosomiasis and malaria. Dams are barriers to migrating fish and to the natural movement of sediments, nutrients, and water—all of which feed the surrounding floodplains and ultimately the sea. (Revenga et al. 1998).

According to McAllister et al. (2001) dams and their associated reservoirs impact freshwater biodiversity by:

- Blocking movement of migratory species up and down rivers, causing extirpation or extinction of genetically distinct stocks or species.
- Changing turbidity/sediment levels to which species/ecosystems are adapted in the rivers affects species adapted to natural levels. Trapping silt in reservoirs deprives downstream deltas and estuaries of maintenance materials and nutrients that help make them productive ecosystems.
- Filtering out of woody debris that provide habitat and sustains a food chain.
- Changing conditions in rivers flooded by reservoirs: running water becomes still, silt is deposited, deep-water zones, temperature and oxygen conditions are created that are unsuitable for riverine species.
- Providing new habitats for waterfowl in particular for overwintering or in arid regions that may increase their populations.
- Fostering exotic species. Exotic species tend to displace indigenous biodiversity.
- Reservoirs may be colonized by species which are vectors of human and animal diseases.
- Flood plains provide vital habitat to diverse river biotas during high-water periods in many river basins. Dam management that diminishes or stops normal river flooding of these plains will impact diversity and fisheries.
- Changing the normal seasonal estuarine discharge that can reduce the supply of entrained nutrients, impacting the food chains that sustain fisheries in inland and estuarine deltas.

- Modifying water quality and flow patterns downstream.
- The cumulative effects of a series of dams, especially where the impact footprint of one dam overlaps with that of the next downstream dam(s).
- Other human activities, including agriculture, forestry, urbanisation and fishing, although these are primarily land-based.

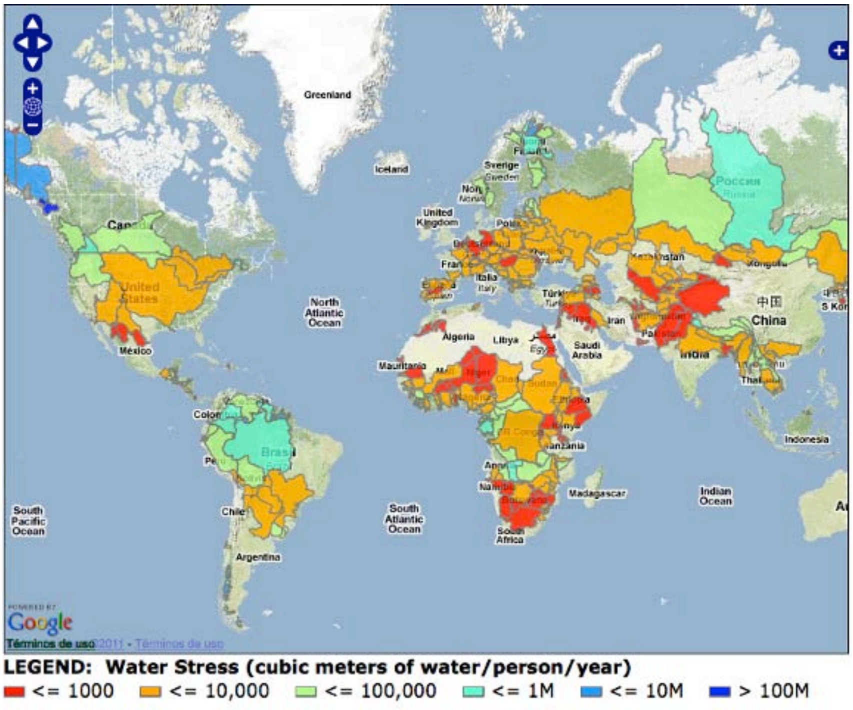
Water over-extraction

Humans withdraw about one fifth of the normal (nonflood) flow of the world’s rivers, but in river basins in arid or populous regions the proportion can be much higher. This has implications for the species living in or dependent on these systems, as well as for future human water supplies (Revenga et al. 2000). The total amount of water withdrawn or extracted from freshwater systems has risen 35-fold in the past 300 years, and since 1960 has increased by 20% per decade. Agriculture accounts for 70% of human water use. In addition, around the world, groundwater is also withdrawn faster than it can be recharged, depleting a once renewable resource (Revenga et al. 1998).

The Rio Grande carries little water compared to other rivers of its length. Typical of rivers that pass through arid regions, it tends to shrink in size as it flows downstream. Most precipitation in the basin falls at either end of the river, as snow near its headwaters or as rain near its mouth (Patiño-Gómez and McKinney 2006). Rio Grande Basin agriculture is highly productive with irrigation claiming more than 85 percent of its water. In addition, population growth and urban water demands in the basin have already increased and are expected to double in the next 50 years. Persistent drought in the region also limits the amount of water available for agriculture and urban uses (RGBI 2010). On average a drought occurs once every seven to ten years (Berger 1995), however a relatively recent drought event lasted more than 10 years (from 1992 to 2003) creating numerous difficulties in the lower Rio Grande basin below Ft. Quitman, Texas (Patiño-Gómez and McKinney 2006).

This region is considered one of the most water stressed areas of the world with less then 500 m^3 of water available per person per year (Tate 2002) (Fig. 30, Table 3). The basin is facing per capita water scarcity and by 2025, will likely descend into further water scarcity (Revenga et al. 2000).

Figure 30. Global Water Stress



Source: <www.transboundarywaters.orst.edu>.

Table 3. Water Stress Indexes

Term	Amount of Water	Results
Relative sufficiency	> 1700 m^3/person/year	
Water Stress	< 1700 m^3/person/year	Intermittent, localized shortages of freshwater
Water scarcity	< 1000 m^3/person/year	Chronic and widespread freshwater problems
Absolute scarcity	< 500 m^3/person/year	

Development by government agencies in the U.S. and in Mexico since 1905 has considerably tamed the flow of the Rio Grande. Because the river has been slowed, stored, rerouted, stabilized, dammed, and diverted, there is little resemblance between turn-of-the-century descriptions of the Rio Grande and today's river. Its flow into the Gulf of Mexico, for instance, is about ten percent of its flow in the early 1900's (Ruesink 1980).

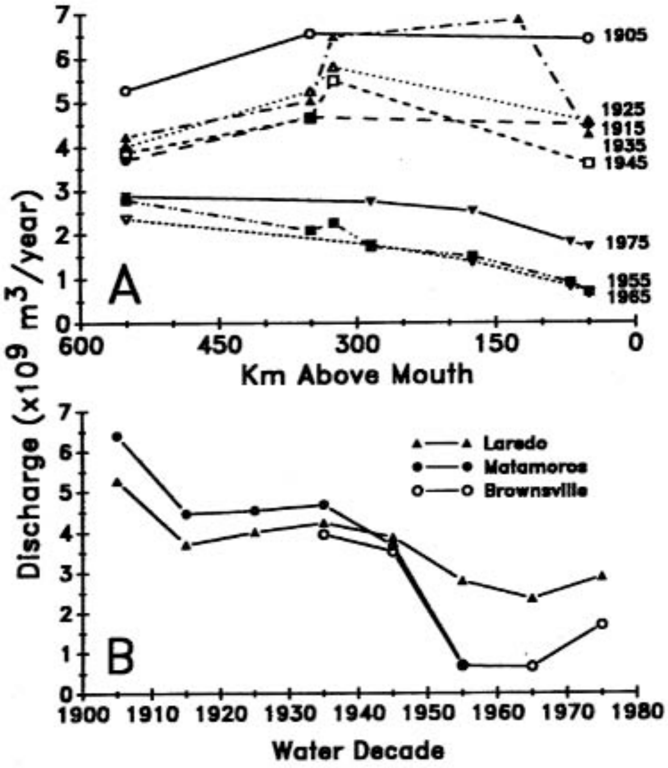
The amount and flow coming into Texas is set by interstate compact and controlled by the Elephant Butte Dam in New Mexico. Irrigation and urban uses in the El Paso area claim so much of the water entering Texas that most of the year the flow is little more than a trickle below El Paso. In addition, several years of low snow pack has dramatically lowered the volume of this important reservoir on the mainstem. With current levels of extraction, this reservoir could be at its lowest in over 50 years, at to 43,172,115 m^3 (Wong et al. 2007).

The Rio Grande is "reborn" 300 miles below El Paso with help from the Rio Conchos in Mexico and the Pecos River in Texas. The highest daily flow recorded above the Rio Conchos confluence was 387,984 L/s (13,700 cubic feet per second) on June 1905. Pre-1962, the river's average flow was 2.9 km^3/year and ocean-going ships used to be able to navigate at least 16 km (10 miles) from its mouth. In 2005, at the last gauge point before the sea, in Brownsville Texas, however, the average flow was 0.44 km^3/year (Wong et al. 2007).

Almost 0.4 million ha (1,544 square miles) are presently irrigated on the United States portion, and a similar amount is irrigated on the Mexican side of the river. The increase over time of irrigated acreage (especially since the 1940s) has had the effect of lessening the flow in the river since water, once removed, does not reenter the river as "return flow." Instead, this water flows into the floodways and irrigation systems and eventually enters one of the Laguna Madre of Texas or Mexico to the northeast or southeast of the river's mouth or merely evaporates into the atmosphere due to the common flood irrigation practices used in this region (Edwards and Contreras-Balderas 1991).

The magnitude of change in water flow over time is easily visualized by comparing the flow at Laredo (mostly above the heavily irrigated lower Rio Grande section) with the flow at Brownsville and Matamoros (immediately below the most heavily irrigated portion; Fig. 31A and B). During severe droughts (e.g., 1950s) the amount used and taken from the river increased dramatically. Although the 1970s water decade was one of the most "water-rich" decades of this century, the yearly average flow of the lower part of the Rio Grande was only one-third to one-half of what it once was (Edwards and Contreras-Balderas 1991). It has been calculated that the water runoff fell from 6.8 m^3 x 10 /year in the 40s to around 2.0—3.0 m^3 x 10 /year in the 1950's, measured near Matamoros/Brownsville, and the runoff declined to around 0 in early 2001 (Contreras-Balderas et al. 2002).

Figure 31. Rio Grande Average Flow, by Decade



Rio Grande flow average flow by decade from gaging-station data of the United States Geological Survey compiled by the Texas Department of Water Resources.
A) Data shown represent all gaging station records from the Laredo gaging station (most upstream locality) to the Brownsville-Matamoros gaging station (most downstream locality).
B) Data from Laredo are above the most intensively irrigated section of the Rio Grande Valley and data from Matamoros- Brownsville are approximately at the downstream end of the most heavily irrigated section.

Source: Edwards y Contreras Balderas, 1991.

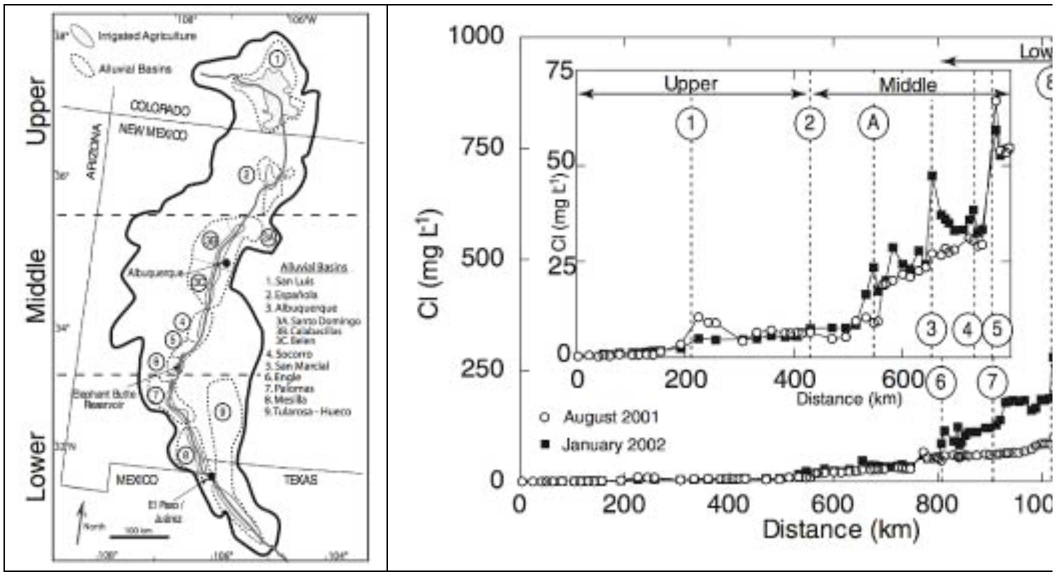
Salinization

The pattern of water use and salinization in the Rio Grande is typical of irrigated rivers in arid climates. In general Cl_2 concentrations along the river increase by about two orders of magnitude (Fig 32).

Currently, 89% of the available water supply is used to support 370,000 ha of irrigated agriculture. Total dissolved solids increase from ~40 mg/L at the headwaters in central Colorado to 500–1500 mg/L at El Paso–Ciudad Juárez on the U.S.-Mexico border, leaving down-river users with water of marginal utility. Although the cause of Rio Grande salinization has been investigated for 75 years, no conclusive answer has been reached. Salinization has been attributed to:

- simple evapotranspirative concentration as the water is reused for irrigation
- displacement of shallow salty groundwater by irrigation
- regional saline groundwater discharge;
- riparian evapotranspiration, and
- unspecified irrigation effects.

Figure 32. Rio Grande Area with Irrigated Agriculture and Alluvial Basins, and Chloride Concentration in the River



a) Map of the Rio Grande area outlining drainage area, river course, irrigated agriculture, and alluvial basins.
b) Chloride concentration versus river distance from the headwaters. Numbers correspond to locations where Rio Grande exits southern end of the alluvial basins shown in the map.

Source: Hogan, 2007.

As ~75% of river flow is lost to open-water evaporation, agricultural transpiration, and riparian transpiration, these processes clearly play a role in salinization. However, recent studies show that that geological sources of salt added by groundwater discharge are more important than agricultural effects (Hogan 2007).

Salinity has been increasing by water removal, irrigation return flows, and structural alterations, especially in lower reaches (Parcher et al. 2010). For several years, salinity content of the waters of the Lower Rio Grande were as much as 700 parts per million of salt, but in the early 1960s, more than 2,500 ppm were flowing through the Rio Grande. In order to overcome the extreme 1960s salinity conditions, a solution was developed by both the United States and Mexico governments through the International Boundary and Water Commission (IBWC). A project consisting of a canal (the Drain) was devised to move the heavily-saline waters originating in Mexico to the Gulf of Mexico before they made it to the Rio Grande. At present approximately 300,000 tons of salt is diverted from the Rio Grande by the El Morillo Drain (Lacewell et al. 2007).

Changes in fish assemblages are thought to be associated to the salinization of certain parts of the river. For example, Edwards and Contreras-Balderas (1991) suggest that the increase in abundance of the cyprinodontids may be related to the apparent change in salinity regimes in the upstream sections of the lower Rio Grande. According to the authors the elevated salinity may provide the appropriate environmental conditions for the successful colonization of these species. While in the lowermost stream segment of the Rio Grande, it appears that the freshwater restricted species have been essentially eliminated and have been replaced by estuarine and marine forms. The increment of secondary (brackish water) and peripheral (marine related) fishes indicates the importance in changes in salinity, reduction of freshwater quantity, or both acting synergically. The disappearance of Nearctic primary fishes, requiring both cool and low salinity water is reflected in this increase in salinity, and an increase in water temperature. This change in fishes also indicates a loss of species requiring coarse particulate bottoms, and is related to a higher turbidity and siltation (Contreras-Balderas et al. 2002).

Cumulative Impacts

The U.S.-Mexican border region has the highest rate of species endangerment in the United States. Some 31 percent of the species listed as endangered by the U.S. Department of Interior are found in the region. On the Mexican side of the border, 85 species of plants and animals are endangered. Not surprisingly, the threats to these species are exacerbated by the fact that the ecosystems in this region are split by a political boundary that greatly complicates conservation efforts (Van Schoick 2004).

Pollutants are having an effect on the indigenous fauna in concert with the observed changes in stream flow (Edwards and Contreras-Balderas 1991). The situation is even more complicated when the increasing salinization of the river is considered as well as the range expansion of populations of non indigenous species already established in different parts of the river. The original freshwater fish communities of the Lower Rio Grande generally retained their integrity until the late 1950s. Species declines in the Rio Grande have been documented as declining or extinct in the Rio Grande since the 60s, such as *Hybognathus amarus*, *Notropis simus* and *Notropis orca* (Contreras Balderas 1975; Bestgen and Platania 1990; Edwards and Contreras-Balderas 1991; Contreras-Balderas et al. 2002).

An worth mentioning example is that of the Rio Grande silvery minnow (*H. amarus*) which was formerly one of the most widespread and abundant species in the Rio Grande basin of New Mexico, Texas, and Mexico, but recent surveys indicated that its current range has been much reduced. In the Pecos River, New Mexico, *H. amarus* had declined by 1968, coincident with establishment of non-native plains minnow (*Hybognathus placitus*), probably by hybridization and competition. In the lower Rio Grande, Texas, downstream of the Pecos River, extirpation of *H. amarus* around 1961 was probably related to construction and operation of Amistad Reservoir and introduction of non-native fishes. Local populations of *H. amarus* (*e.g.*, Rio Grande near Big Bend, Texas) were considered extirpated just after 1960. *H. amarus* survives only in New Mexico in 5% of its original range from Cochiti Reservoir downstream to Elephant Butte Reservoir (Bestgen and Platania 1991).

Similarly, hydrological and physical habitat alteration and introduction of nonnative fishes have been suggested as the factors most commonly associated with the marked decline in range and numbers of most native fish species in the Southwest (Miller 1961, Rinne 2003a) and Upper Rio Grande (Hoagstrom et al. 2010). As a result, the majority of the southwestern fish species have been officially listed as threatened or endangered (Rinne 2003b).

Schmitt et al. (2004) summarize the following cumulative impacts of physical and chemical changes together with the introduction of exotic species, such as salt cedar (*Tamarix aphylla*) on the river-dependent biota in the Rio Grande Basin. The exposure to multiple environmental stressors of different magnitude and duration has profoundly affected the native Rio Grande biota, consequently some taxa have been extirpated, some have received Federal protection, and others have been proposed for Federal listing. The shovelnose sturgeon (*Scaphirhynchus platorhynchus*), American eel (*Anguilla rostrata*), phantom shiner (*Notropis orca*), and the Rio Grande bluntnose shiner (*Notropis simus simus*) have been extirpated from portions of the Rio Grande, and the latter is federally listed as threatened. The Rio Grande silvery minnow (*H. amarus*), Big Bend gambusia (*Gambusia gaigei*), and Pecos gambusia (*G. nobilis*) are endangered, and the Pecos pupfish (*Cyprinodon pecosensis*) has been proposed for Federal listing; the latter two species now exist only at Bitter Lake National Wildlife Refuge, where elevated concentrations of selenium have been reported (unpublished data, USFWS, Albuquerque, NM). Selenium and pesticides from agriculture and mercury from historical cinnabar mining in the Terlingua District have been implicated in the reproductive failure of the Trans-Pecos population of peregrine falcons (*Falco peregrinus*), a threatened species, in areas adjacent to the Rio Grande. The Southwestern willow flycatcher (*Empidonax traillii extimus*) is endangered primarily because its riparian habitat along the Rio Grande and Pecos River has been eliminated by the operation of water projects. Small populations of the endangered interior least tern (*Sterna antillarum athalassos*) nest at Amistad and Falcon reservoirs and at Bitter Lake NWR, and ocelots (*Leopardus pardalis*) and jaguarundi (*Herpailurus yaguarondi*), both endangered, frequent riparian brushlands adjacent to the Rio Grande and other waterways and inhabit Laguna Atascosa NWR. An experimental population of the endangered whooping crane (*Grus americana*) was established at Bosque del Apache NWR, which winter at the refuge along with other migratory species. Wetlands in the western Texas parts of Pecos River Basin also host breeding populations of the threatened white-faced ibis (*Phlegadis chihi*). Bald eagles (*Haliaetus leucocephalus*) nest at Elephant Butte and Caballo reservoirs in New Mexico and over-winter along much of the Rio Grande, and brown pelicans (*Pelecanus occidentalis*), whooping cranes, and Eskimo curlews (*Numenius borealis*) frequent the Laguna Madre. American white pelicans (*Pelecanus erythrorhynchos*), which were proposed for federal listing, also reside at Falcon Reservoir. Other federally listed plants and animals occur in the Rio Grande corridor but are not exclusively associated with riparian habitats.

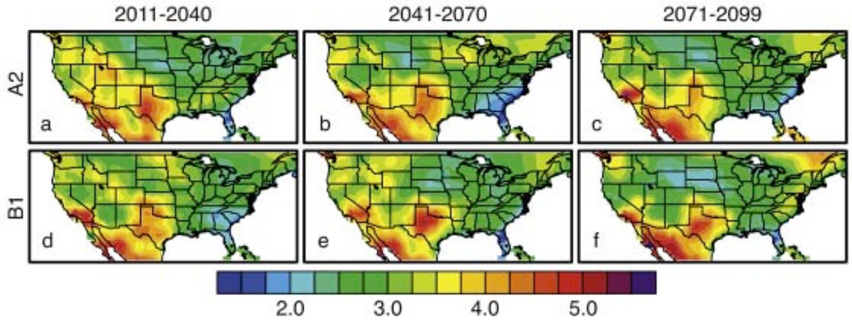
Alteration of water quantity and river flow regimes associated with water management is one cause of the imperilment of aquatic birds. There is concern that the proposed modification of Lower Rio Grande irrigation systems from open canals to pipelines may further restrict water availability for aquatic birds, both directly, by reducing surface area of open canals, and indirectly, by reducing runoff into the Rio Grande Wildlife Refuges Complex (RGWRC); due to the functions and services that the RGWRC provides to wildlife (habitat availability for stopover, protection, perching, feeding and reproduction), it plays an important role in maintaining bird diversity in the region (Weir et al. 2006).

Climate change impacts

Water is widely regarded as the most essential of natural resources, yet freshwater systems are directly threatened by human activities and stand to be further affected by anthropogenic climate change. According to a consensus of 15 models (Fig. 33), the strongest U.S. hot spot by far stretches across the Southwest from southern California to west Texas and intensifies even more over northern Mexico. Hotspot distribution is strongly influenced by changes in seasonal precipitation variability (Diffenbaugh et al. 2008).

Current predictions of climate change include less snowpack earlier snow melt, and higher evaporative demands and the resulting in lower spring runoff, more intense localized precipitation events, and warmer conditions for the Rio Grande watershed (Kerr 2008). Average air temperatures indicate that rainfall has dropped to 67% of the historical average for El Paso, 70% for Amistad Reservoir to Falcon Dam, 64% from Falcon Dam to Rio Grande City, and 68% from this city to the delta. Air temperatures are 0.7°C above the historical average, and evaporation has increased 124% (Contreras-Balderas et al. 2002).

Figure 33. Sensitivity Models to Climate Change with Two Emissions Scenario



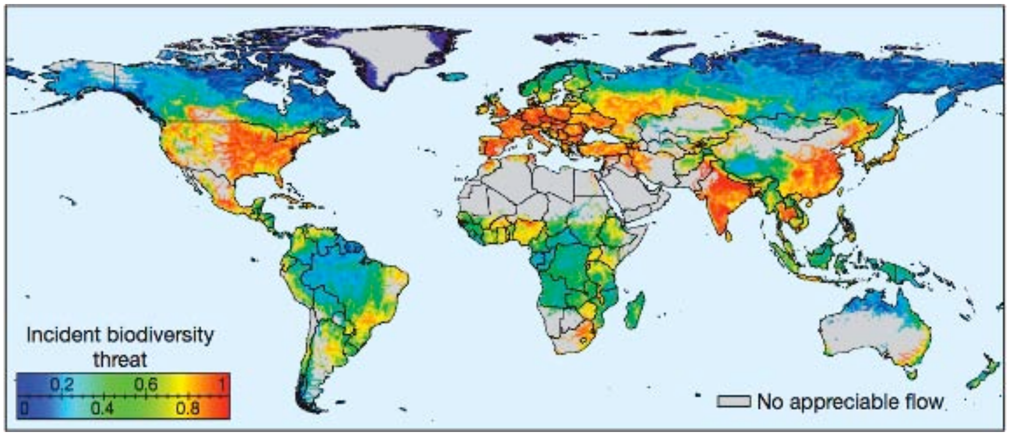
Models predict that the U.S. Southwest and northern Mexico will be most responsive (reds and yellows) to the strengthening greenhouse. Sensitivity of aggregate climate change scores to greenhouse gas concentration and pathway: (top) results for the A2 emissions scenario and (bottom) results for the B1 emissions scenario. The aggregate Standard Euclidean Distance (SED) scores are shown for three three-decade periods of the 21st century. Unitless.

Source: Diffenbaugh *et al*., 2008.

The resulting change in runoff will affect vegetative cover in the watershed and habitat for various species. Substantial changes in the natural hydrograph and intensification of managed uses will severely disrupt stream ecology and health, which may have additional implications for managing the endangered Rio Grande Silvery Minnow (Hurd and Coonrod 2007).

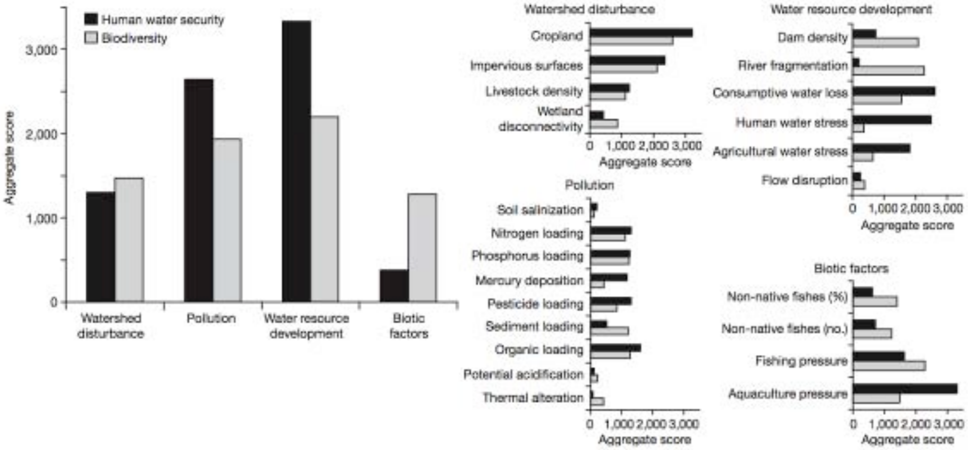
Other models also point out a severe threat to biodiversity occurring in the Rio Grande delta (Fig. 34). Actually, the driver contributions in areas where incident threat exceeds the 75th percentile, as is the case with this region, have a close match with the drivers of change of biodiversity in the lower Rio Grande and its delta (Fig. 35).

Figure 34. Global Geography of Incident Threat to Biodiversity



Source: Vörösmarty et al., 2010.

Figure 35. Drivers of Change of Biodiversity in the Lower Rio Grande



Theme and driver contributions in areas where incident threat exceeds the 75th percentile. High incident threat typically arises from the spatial coincidence of multiple themes and/or drivers of stress acting in concert.

Source: Vörösmarty et al., 2010.

Water is the critical factor in this environment and is seriously threatened by development of the Lower Rio Grande. It is clearly necessary to establish policies and actions that will restore the quality and quantity of river water and its associated biota, especially fishes, to the highest possible level (Contreras-Balderas et al. 2002). Alliance between both U.S. and Mexican scientists and government officials in developing technical solutions and greater conservation awareness are urgent and critical steps toward preserving one of the most important watersheds in North America. Rivers must no longer be seen only as water supplies, but must be valued for their own sake. Both the United States and Mexico should pass legislation recognizing international rivers, dedicating water to them, and allowing the purchase of water to maintain their flows all the way to their mouths. The legislation should include consideration of drought and flood years, as well as long-term global climate change predictions (Van Schoick 2004).

Invasive Species in the Río Bravo/Laguna Madre Ecoregion

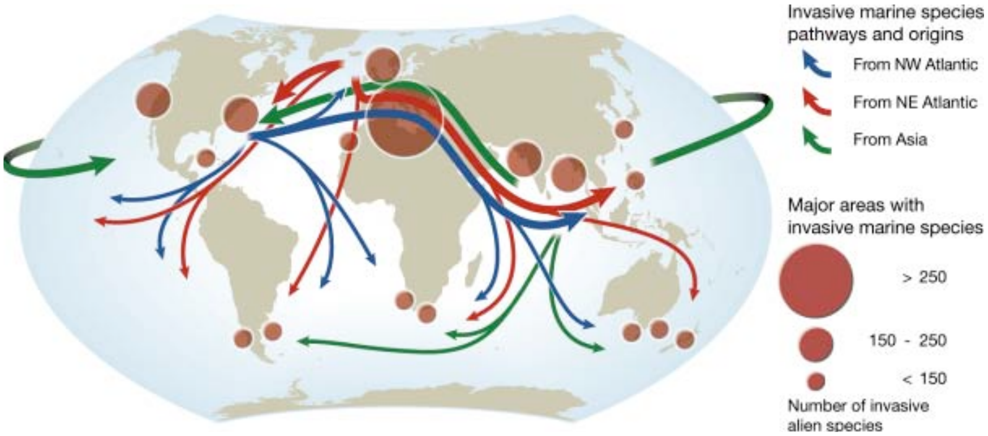
Alien invasive species (AIS), defined as those species whose introduction does or is likely to cause economic or environmental harm or harm to human health, are found in all taxonomic groups and virtually every ecosystem type, and every region of the world has been affected to some extent. Invasive species share common characteristics including, but not limited to, one or more of the following traits: rapid growth rate, efficient dispersal capabilities, large reproductive output and tolerance to a broad range of environmental conditions. Introduction and establishment of invasive species is an accelerating problem worldwide as a result of increased trade, travel and transport of goods. Not only has the rate of these activities increased but also the distances covered are greater over a shorter span of time (Campbell 2005). Biological invasion is second only to habitat destruction as the greatest threat to native species and loss of biodiversity worldwide. The economic, social, recreational and ecological losses/costs attributable to aquatic invasive species are difficult to quantify. While some costs have been estimated, such as the US$5 billion in damages to water pipes, boat hulls and other hard surfaces caused by zebra mussels in the Great Lakes, others, such as the loss of native species and environment restoration to pre-invasion quality, are unknown (Buck 2007). The ecological impacts of AIS span all levels of biological organization from the genetic level to large ecosystem level, as well as produce cascading effects that impact food web interactions and ecosystem processes (Ciruna et al. 2004).

The Millennium Assessment confirms that AIS have been one of the main drivers of biodiversity loss over the last 50 to 100 years and further states that the trend will continue or even increase in biomes worldwide (UNEP 2005a, 2005b). The resulting cost will include the loss of native species and reduction of biodiversity, and impairment of ecosystem functioning and services, thus affecting livelihoods.

There is general agreement that the problems caused by alien invasive species are especially acute in geographically and evolutionarily isolated systems such as islands and other remote areas such as lakes and isolated streams. For example, 67% of globally threatened oceanic bird species affected by AIS are found on islands. Freshwater ecosystems are also seriously affected by AIS; for freshwater fishes globally, preliminary analysis points to alien invasive species as having contributed to 50% of known species' extinctions (Baillie et al. 2004). In the marine environment, alien invasive species have been rated as one of the greatest threats to the world's oceans. A variety of taxonomic groups, such as protozoa, sponges, cnidarians, flatworms, polychaete worms, mollusks, crustaceans, bryozoans, tunicates, fish, and seaweeds, have contributed to major invasions in recent years (UNEP 2001). Increases in shipping worldwide have made it the most important pathway for the spread of alien invasive species. Alien invasive species can attach to surfaces of ships, boats, and drilling platforms (usually as communities of fouling organisms) and are transported in ballast water, ballast sediment, and sea chests.

Impacts from AIS on biodiversity can be direct, indirect, and cumulative (De Poorter et al. 2007).

Figure 36. Major Pathways and Origins of Infestations of Invasive Species in the Marine Environment

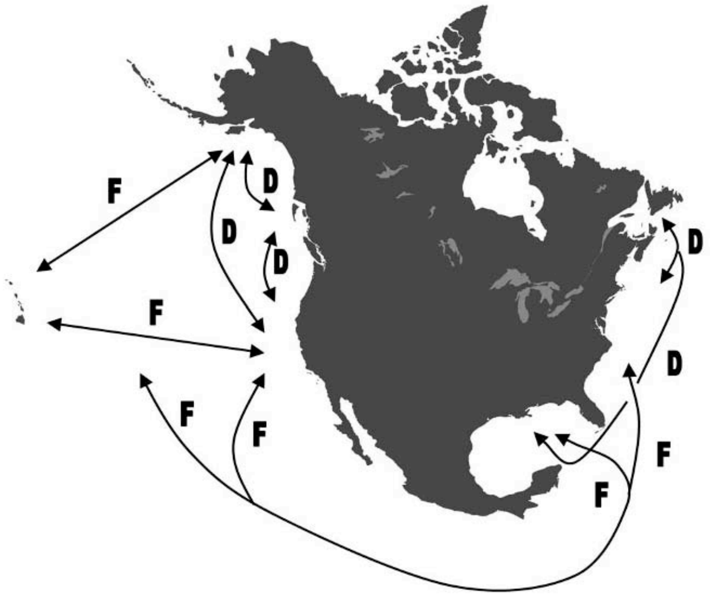


Source: PNUMA/GRID-Arendal, 2009.

Pathways

There is an increasing awareness that the different mechanisms through which alien species become introduced from one location to another play a pivotal role in the subsequent likelihood of biological invasion (Ruiz and Carlton 2003). A pathway, or vector, is the means by which a species enters an ecosystem (Fig. 37). Pathways for introductions of non-indigenous aquatic species can be divided into three categories, according to Williams and Meffe (1998): a) *unintentional* (e.g., a billion tons of ballast water per year and at least 10,000 species daily are being transported around the world (Carlton 1999); b) *intentional* (aquaculture and aquarium trade have been considered as major pathways of aquatic invasive species introductions) (Welcomme 1992), e.g., the introduction of tilapia worldwide (Canonico et al. 2005) and the introduction of snakeheads in several countries (Courtenay and Williams 2004); c) *escape from confinement* (e.g., the first documented release of lionfish in the eastern United States took place in Florida on 24 August 1992. Six lionfish were freed when Hurricane Andrew destroyed a large marine aquarium on a waterfront porch at the edge of Biscayne Bay (Ruiz-Carus et al. 2006).

Figure 37. Foreign and Domestic Arrival Designations for Ships Calling on Ports of the United States and US Protectorates



Foreign (F) and domestic (D) arrival designations for ships calling on ports of the United States and US protectorates. (Note: although not depicted on this map, transits between individual US Caribbean islands were considered domestic, while all traffic to and from the Caribbean was deemed to be foreign.)

Source: Ruiz at al. 2001.

Alien species may arrive and enter a new region through three broad mechanisms: importation of a commodity, arrival of a transport vector, and/or natural spread from a neighboring region where the species is itself alien. Natural pathways include wind, currents and other forms of dispersal in which a specific species has developed morphological and behavioral characteristics to employ. Man-made pathways are those that are enhanced or created by human activity. Releases of vertebrates through pathways tend to be characterized as deliberate releases, while releases of invertebrates are considered as contaminants, and plants as escapes, while pathogenic microorganisms are generally introduced as contaminants of their hosts (Hulme 2008). The Convention on Biological Diversity (CBD) separates 'intentional introductions,' which refer to the deliberate movement and/or release by humans of an alien species outside its natural range (past or present), from 'unintentional introductions,' which describes all other introductions that are not intentional (Miller, Kettunen and Shine 2006)

Unintentional Pathways

Either man-made or naturally occurring pathways can unintentionally move organisms.

Shipping

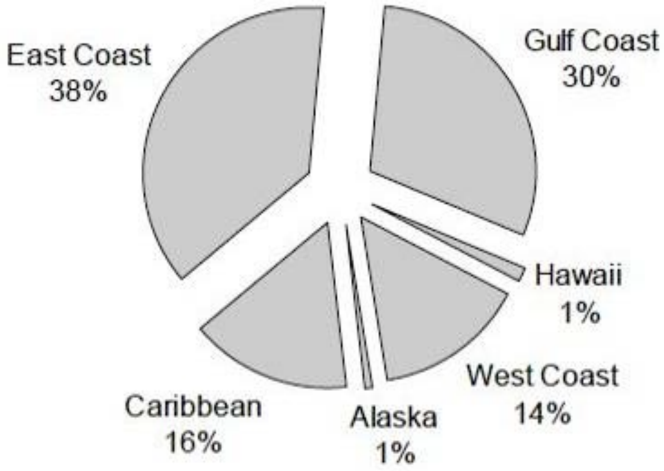
Shipping encompasses two primary vectors for the introduction of marine species—transport in ballast water and by hull fouling. The study of these vectors is, in effect, the behavioral and population ecology of ships.

In the United States, under the National Invasive Species Act of 1996 (NISA), Congress directed the Secretary of Transportation to promulgate regulations that: (a) require vessel masters to report their ballast management practices when entering US waters from beyond the 200-mile Exclusive Economic Zone, EEZ, and (b), describe a suite of voluntary ballast water management practices for use by such vessels. The voluntary guidelines include holding ballast water on board and open-ocean exchange (flushing) of ballast tanks that will be discharged in US waters. The management practices are intended to: (1) minimize the transfer of non-indigenous species in ballast water of ships and (2) reduce the risk of exotic species invasions associated with the release of ballast water.

From July 1999 to June 2001, only 30.4% of the vessels that entered US waters from outside the EEZ filed mandatory reports with the National Ballast Water Information Clearinghouse, as required by the US Coast Guard (Fig. 38). Due to the poor nationwide reporting rate, it was difficult to estimate reliably: (a) the patterns of ballast water delivery and (b) the compliance with voluntary guidelines for ballast water management (Ruiz et al. 2000). As a result, regulations have changes and are currently under review.

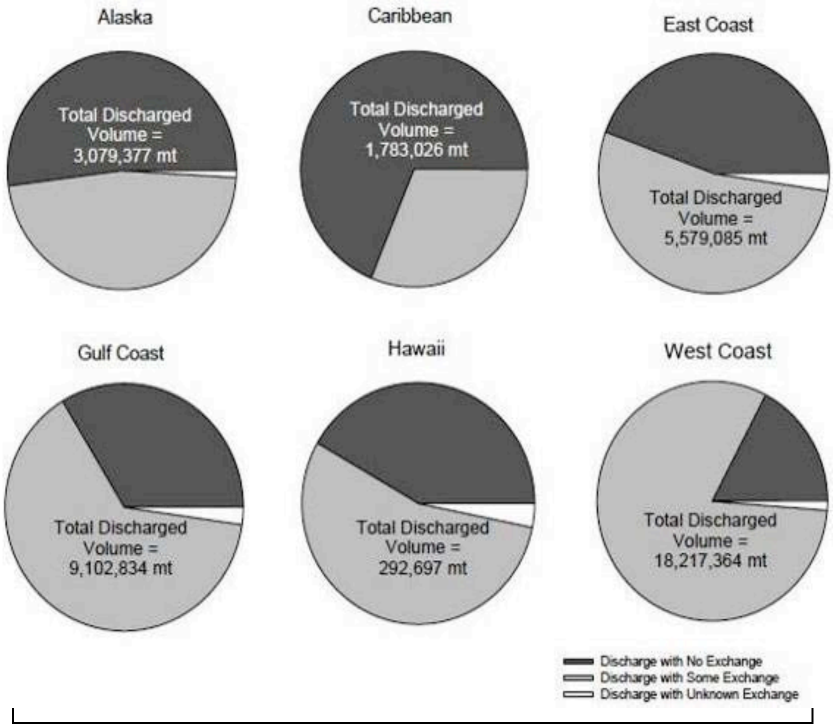
Of the 28,988 foreign arrivals that submitted reports from 1 July 1999 to 30 June 2001, 73.6% indicated no intention to discharge ballast water within US territory, 12.9% declared no exchange of ballast water prior to discharge and 13.0% of the reporting vessels declared some degree of ballast water exchange prior to discharge (Fig. 39). Thus, of the 7,652 vessels that reported discharge of ballast water in US waters, about half (51.2%) indicated some degree of mid-ocean exchange and 48.8% indicated discharge with no prior exchange. Nationwide, approximately 29.7% (11.1 million metric tons, or mt^3) of the ballast water from foreign arrivals was reported as discharged into the United States without undergoing any exchange. Of the vessels that reported no intent to discharge ballast water upon arrival, most carried ballast water. Only 12.8% (3,712 of 21,336 vessels) was reported as No Ballast on Board, or NOBOB.

Figure 38. Percent Foreign Arrivals by Coast, 1999-2001



Percent foreign arrivals traffic by coast over two-year period from July 1999 to June 2001 (n= 95,471 arrivals). Data are from MARAD arrival reports from 1 July 1999 to 30 June 2001. *Source:* Ruiz et al., 2001.

Figure 39. Proportion of Ballast Water Discharged by Coastal Region and Management Strategy



Ballast Survey Database (July 1999 to June 2001).

Source: Ruiz et al.. 2001.

The number of invasions resulting from shipping has increased exponentially through time, according to data collected by the National Ballast Information Clearinghouse to delineate invasion patterns, transfer mechanisms, and pathways. In 2005, ships in the Gulf of Mexico were a 50:50 mix of domestic and those from overseas, and most were tankers. In addition to ballast water, the hulls of these ships represent more than 200 million m2 of wet surface area that can act as potential surface for fouling species. In addition, thirteen million metric tons of ballast water were discharged into the Gulf. The last ports of call for these ships, and thus the potential points of origin of any invading species, are distributed throughout the world (Miller 2007). On 13 February 2004, the Mexican Ministries of Environment and Natural Resources, Transport, Finance, and Foreign Affairs, and the Mexican Navy adhered to the International Convention for the Control and Management of Ships' Ballast Water and Sediments (IMO-BWM) in order to overcome limitations in the implementation and enforcement of existing policies and laws for reducing AIS. The Convention will enter into force 12 months after its ratification by 30 countries, representing 35 percent of world merchant shipping tonnage. At the present, the Convention has not yet entered into force. However, Mexican authorities have contemplated preventive measures, such as ballast water exchange in open ocean waters.

Oil Platforms

At the present, there are some 4,000 major platforms in the territorial waters of the Gulf. These platforms have become highly valued artificial reefs hosting a diverse biofouling community, associated motile epifauna and numerous fish species. These habitats may also harbor an array of invasive species. Overall, 11 species of scleractinian corals have been found on the platforms, including *Oculina patagonica* (Bitar and Zibrowius 1997; Salomid et al. 2006; Sartoretto et al. 2008) and *Tubastrea coccinea* (Cairns 2000) and the colonial ascidian, *Didemnum perlucidum* (Sammarco 2007); however, comprehensive surveys have not been conducted since the early 1980s. The taxonomy of the historical surveys needs to be updated while the taxonomic experts used in these older studies are still available and new surveys need to be conducted (Gallaway 2007).

Boat Trailers and Recreational Activities

Overland transport of boats on boat trailers is a common pathway for the unintentional introduction of non-indigenous aquatic species. This would appear to be a significant pathway in the Gulf region, as warm weather makes year-around boating and fishing possible. In addition to boating and fishing, Scuba diving, harvesting of bait, jet skiing, seaplane pontoons, recreational boating, and even waterfowl hunting serve as pathways (Federal Register 2000, Barrett-O'Leary et al. 2001).

Cross-basin Connections

From small channels to major intercoastal waterways, new connections between isolated water bodies have allowed the spread of many invasive species (EPA 2009). One vector of special concern in the State of Texas is interbasin transfers of water. With water development infrastructure being constructed throughout Texas, the potential for rapid transfers of biota between river basins, and thus coastal bays, is increasing.

Non Target Species-Stock Contamination

A great number of fishes and other aquatic organisms have been introduced as “contaminants” or “byproducts” associated with the intentional introduction of target species (Barrett-O'Leary et al. 2001). Pitman (2003) mentions several examples: for instance, a highly invasive species such as gizzard shad, *Dorosoma cepedianum.* A small stock of about 1000 gizzard shad introduced into Lake Havasu on the Lower Colorado River created a population that rapidly spread throughout the river and related canals and into Mexico in just 18 months. In another location, in Pennsylvania, gizzard shad were accidentally introduced with a stocking of American shad (Denoncourt et al. 1975).

The rapid spread of Asian carp throughout the Mississippi River basin is well documented. Records reveal how easily these species spread as non-target contaminants. Native to Asia, the black carp, *Mylopharyngodon piceus,* first arrived in the United States as a non-target contaminant within a shipment of grass carp (Nico and Williams 1996). The silver carp, *Hypophthalmichthys molitrix,* was imported in 1973 for phytoplankton control in eutrophic water and as a food fish. This species hitchhiked to Florida in a shipment of grass carp for vegetation control (Middlemas 1994).

Transported Commodities

Many aquatic species are transported each year as unintentional contaminants of global trade. Seas and other water bodies have for millennia connected human populations, serving as routes for transportation of people and their goods as well as for merchandise, and today more than 90% of all trade goods worldwide are transported on the ocean (IMO 2008).

However, the continued growth of global trade, the modernization and application of more sophisticated technologies in ships, and the ever-increasing movement of ships between different parts of the world at greater speeds has implications for the environment as well as human wellbeing. Numerous species are transported every day in ballast water and ballast sediment and a subset of these will become invasive. For example, the freshwater zebra mussel, native to Europe, has become a prolific invader, spreading to the United States in ballast water and is now found throughout the waterways of North America. Zebra mussels encrust any solid structures in the water and block water pipes, and the estimated cost of dealing with them may be as high as US$1 billion per decade. The North American comb jellyfish was introduced into the Black Sea through ship ballast water in the early 1980s. By the early 1990s, the area's anchovy fishery had been almost decimated and annual losses caused by the declining catches of commercially marketable fish amounted to at least US$240 million (Tamelander et al. 2010).

Intentional Pathways

Intentional pathways result from deliberate actions to translocate an organism.

Aquaculture and Fisheries

In the Southeast Region (coastal states from South Carolina to Texas), approximately two-thirds of the aquatic (freshwater and marine) introductions are attributable to intentional pathways: stocking, aquaculture escapes, bait releases, and aquarium releases. Almost half of these come from marine introductions, with the largest percentage attributable to aquarium releases. The incidence of marine fish introductions was extremely low until the 1990s. Since then, more than 20 species have been released, including a variety of angelfish, groupers, butterflyfish, and some traditionally freshwater species that are very salt tolerant, such as cichlids. Eleven species have been found in the Gulf. Additionally, at least three species of shrimp have escaped aquaculture in the region and there is a risk of some cultured bivalves escaping (Fuller 2007).

Recreational Sport Fishing

Nearly one-half of the non-indigenous freshwater fishes that have been intentionally introduced in North America were released to establish sport fisheries and to diversify angling opportunities (Fuller et al. 1999, Crossman and Cudmore 2000). Sport fishes are introduced to address a number of recreational issues—absence of sport fish species in a particular water body, demand to introduce more desirable and familiar sport species, and introduction of hardier species when native habitats become unsuitable for indigenous species. Stock contamination and stock misidentification have caused unintended species' releases (Barrett-O'Leary et al. 2001). For example, many putatively native populations of greenback cutthroat trout (*Oncorhynchus clarkii stomias*) were actually another subspecies of cutthroat trout, the Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*). The error was due to the introduction of Colorado River cutthroat trout throughout the native range of greenback cutthroat trout in the late 19th and early 20th centuries from fish stocking activities (Metcalf et al. 2007).

Forage Species

To compensate for potential inadequacies in the natural food supply for introduced sport fishes—both native and non-native—forage fishes and other prey species (e.g., mysid shrimp) have been introduced into numerous lakes, reservoirs, and rivers (Barrett-O'Leary et al. 2001).

Baitfish Production

Commercial baitfish harvesters have “seeded” ponds and small lakes with non-indigenous baitfish species to create a population that can be regularly, and often exclusively, harvested (Barrett-O'Leary et al. 2001).

Bait Bucket Releases

Bait buckets have served as an active pathway for fish introductions. More recent introductions of baitfish can be attributed to many newly developed sport fisheries. Many anglers dump bait buckets at the end of the day as a way of disposing of bait or with the assumption that it will become food for sport fish. It is estimated that 109 fish species have been introduced to US waters through bait-bucket (Barrett-O'Leary et al. 2001). According to Benson (2000) three amphibians, seven crustaceans and 84 fish have been introduced through this pathway in the Gulf of Mexico region. From these, 34 turned invasive in the Laguna Madre Ecological Region.

Biological Control

One of the reasons that some non-native species can become invasive is that the natural controls (e.g., competitors, predators, and pathogens) that kept them in check in their native habitat are not present in the invaded ecosystems. Sometimes these natural biological control agents from their native habitats can be brought over to control them in their new home as well. If the agent is truly selective and harms only the non-native species that it is intended to control, this can work well. However, sometimes the new introduction can cause other problems of its own and compound the situation by causing additional harm to native species or their habitats (USFW 2009).

Regional and National Initiatives

Different recent regional and national initiatives to prevent the entry and dispersal of invasive species and to control or eradicate them from North American ecosystems are been set. The following are some examples:

One of the goals of the Strategic Plan for North American Cooperation in the Conservation of Biodiversity is to:

- Promote collaborative responses to threats facing North American ecosystems, habitats and species.
  - Within this specific goal, a key priority area for action is to promote the development of concerted efforts to combat alien invasive species on a bi- or trilateral basis in North America.
  - The CEC has been accomplishing this during several years through different workshops and projects.[12]

Among the goals, objectives and tasks of the Strategic Plan of the Gulf of Mexico and South Atlantic Regional Panel of the Aquatic Nuisance Species Task Force of the United States (GMSARP 2005-2009), the following stand out for emphasizing the cooperation of the US and Mexico on this matter:

- Goal 1. Invasive species coordination and Planning throughout the Gulf of Mexico Region, including Mexico.
  - Objective 2, task 3. The GMSARP will encourage state and federal agencies to incorporate Mexico in future regional management plan objectives as appropriate.
- Goal 2, Objective 2. The GMSARP will establish and maintain a working relationship with Mexico.

Article 1 of the North American Plant Protection Agreement of October 1976 cites: “To encourage cooperative efforts among the member countries (US, Mexico and Canada) to prevent the entry, establishment and spread of quarantine pests and to limit the economic impact of regulated non-quarantine pests while facilitating international trade in plants, plant products and other regulated articles; and to encourage and participate in similar hemispheric and global cooperative efforts” (NAPPO 1976).

In the same way, the cooperation between the US and Mexico is stressed in the draft of the National Strategy to Prevent, Control and Eradicate Invasive Species in Mexico (Conabio 2009). For the region, there are three strategic plans at the state level:

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[12] Examples include *Preventing the Introduction and Spread of Aquatic Invasive Species in North America*; *Status, Environmental Threats, and Policy Considerations for Invasive Seaweeds for the Pacific Coast of North America*; *Closing the Pathways of Aquatic Invasive Species across North America*; *An Unwelcome Dimension of Trade: The Impact of Invasive Species in North America*; and *Trinational Risk Assessment Guidelines for Aquatic Alien Invasive Species*; among others (CEC 2001, 2003b; Murray et al. 2007; Mendoza et al. 2009).

- The State Management Plan for Aquatic Invasive Species in Louisiana (Louisiana Department of Wildlife and Fisheries, Louisiana Sea Grant, Louisiana Aquatic Invasive Species Task Force, McElroy and Barrett-O'Leary 2004).
- The Texas State Comprehensive Management Plan for Aquatic Nuisance Species (TPWD-Chilton et al. 2006).
- The Conservation Plan of the Laguna Madre of Tamaulipas, which includes a strategic objective to control abundance and dispersal of invasive species in the Natural Protected and its area of influence (TNC-Pronatura-Conanp 2009).

Methodology

Exotic and Invasive species in the LM/RBD Ecological Region

An extensive search through authoritative sources of information was made (e.g., NAS-USGS, Conabio, Conanp, GSMFC-GSARP-AIS, ISSG, etc.), official management plans, and other specialized sources (journal articles, theses, books, reports, etc.), for reports on aquatic exotic and invasive species within the extent of the proposed ecological priority region (Region 11), which includes the US states of Louisiana and Texas and the Mexican state of Tamaulipas and Veracruz.

Veracruz was included because most studies of the Laguna Madre in Mexico include this state.

As mentioned before, this ecoregion does not refer to the Laguna Madre exclusively but to an ecoregion corridor, the Laguna Madre and Rio Bravo delta corridor, that includes terrestrial and freshwater environments.

All the species reported were compiled on a database and categorized in six major groups; plants, invertebrates, fishes, amphibians and reptiles, mammals, and others (viruses, bacteria, protozoa and fungi). Once this list was integrated, fact sheets for each species were prepared with the necessary information to perform analysis on the subsequent pathway.

Ecological Niche Modeling

Occurrence Records

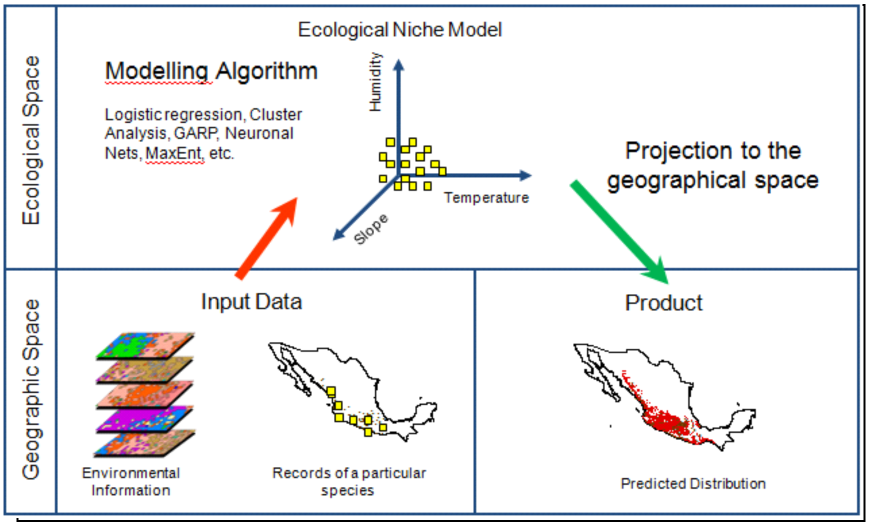
To analyze the occurrence of species with invasive records worldwide that are present in Region 11, georeferenced records were gathered from different sources, including the Global Biodiversity Information Facility (GIBIF), Lifemapper (US NSF EPSCoR), the Non-indigenous Aquatic Species database (USGS-NAS), and the Mexican National Commission for the Knowledge and Use of Biodiversity (Conabio). The records were compiled and, after eliminating any duplicates, were saved for each species as comma-delimited files (.csv).

Modeling Methods

A problem encountered in dealing with invasive species is that there is often a lack of sufficient biological and ecological information to support making decisions that might eliminate or reduce the biodiversity loss rate. This is where new methodological approaches such as biodiversity informatics can allow the generation of useful information from incomplete data.

The ecological niche and geographical distribution modeling of the species (Fig. 40) can be better understood from Hutchinson's functional niche approach (Hutchinson 1957), which considers a niche as an n-dimensional hypervolume, where each point on the environmental axis describes the resources that allow the species to survive indefinitely.

Figure 40. Species Ecological Niche and Geographical Distribution Modeling



Adapted from Martínez-Meyer 2009.

Martínez-Meyer (2009) states the following concepts to explain the abovementioned considerations:

1. The species acts according to ecological rules that determine its geographical distribution.
2. A point in the geographical space corresponds to only one point in the ecological space; otherwise each point in the ecological space could have more than one point in the geographical space.

3. Ecological niches tend to be evolutionarily stable for different taxonomic groups.[13]
4. Species are subject to ecological rules that determine their geographical distribution, independently of the geographic context.

We opted to apply two modeling algorithms; the Genetic Algorithm for Rule-Set Prediction (GARP) and the Maximum Entropy Method (Maxent) in order to predict which areas within the region would satisfy the requirements of the species' ecological niche and thus the species' potential distribution (Anderson and Martínez-Meyer 2004). The potential distribution describes those conditions suitable for the survival of the species and is therefore of great importance for the invasive species risk assessment process.

The Genetic Algorithm for Ruleset Prediction (GARP) (Stockwell and Peters 1999) was selected because it has been successfully applied in past studies focused on different ecological issues, such as global warming, infectious diseases, and invasive species (Arriaga et al. 2004, Phillips et al. 2004). GARP was also chosen because it is one of the few methods available that does not require absence data (negative examples).

GARP searches iteratively for non-random correlations between species presence and absence and environmental parameter values, using several different types of rules. Each rule type implements a different method for building species prediction models (Stockwell and Peters 1999).

On the other hand, Maxent was chosen because it has efficient deterministic algorithms that are guaranteed to converge to the optimal (maximum entropy) probability distribution, its probability distribution has a concise mathematical definition, and is therefore amenable to analysis and the output is continuous, allowing fine distinctions to be made between the

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[13] The full range of environmental conditions (biological and physical) under which an organism can exist describes its fundamental niche. As a result of pressure from and interactions with other organisms (e.g., superior competitors), species are usually forced to occupy a niche that is narrower than this, and one to which they are mostly highly adapted. This is termed the "realized niche." The ecological niche has also been termed by Hutchinson a "hypervolume," which defines the multi-dimensional space of resources (e.g., light, nutrients, structure, etc.) available to (and specifically used by) organisms. Hutchinson proposed that one could characterize the ecological niche of a species as an abstract mapping of population dynamics onto an environmental space, the axes of which are abiotic and biotic factors that influence birth and death rates. If a habitat has conditions within a species' niche, a population should persist without immigration from external sources, whereas if conditions are outside the niche, it faces extinction. Analyses of species' niches are essential to understanding controls on species' geographical range limits and how these limits might shift in our rapidly changing world (Holt 2009).

modeled suitability of different areas. Finally, Maxent is a generative approach, rather than discriminative, which can be an inherent advantage when the amount of training data is limited, as was the case for a considerable number of the species in this analysis.

Maxent as a general-purpose method for making predictions or inferences from incomplete information, estimates a target probability distribution by finding the probability distribution of maximum entropy (i.e., that is most spread out, or closest to uniform), subject to a set of constraints that represent our incomplete information about the target distribution (Phillips et al, 2006).

Environmental Variables and Model Building

To generate potential geographic distributions for the reported species we used the interpolated climate surfaces for global land areas (excluding Antarctica) at a spatial resolution of 10 arcminutes (18.6 km x 18.6 km = 344 km^2 at the equator), considering only current conditions (interpolations of observed data, representative of the period from 1950–2000), generated by Hijmans et al. 2005 (www.worldclim.org). The climate layers considered were altitude, monthly total precipitation, monthly mean, minimum and maximum temperatures, and 19 derived bioclimatic variables.

Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters) (Hijmans et al. 2005).

Global coverage oceanic layers with half-degree cell resolution compiled by Kaschner et al. 2008 (www.aquamaps.org/data) were used to model potential niches of marine species and to complement the analysis made for freshwater and estuarine species reported as occurring in marine environments. Variables considered for analysis were: maximum depth in meters, minimum depth in meters, mean annual sea ice concentration, mean annual distance to land in kilometers, mean annual primary production (chlorophyll A) in mg C per square meter per day, mean annual bottom salinity in practical salinity units (psu), mean annual surface salinity in psu, mean annual bottom and mean annual surface temperatures in degrees Celsius.

If the minimum depth of the species range equaled or was less than 200 m, then only surface layers for temperature and salinity were used. Bottom layers were used for species with depth ranges greater than 200 m, and combined with surface layers for species that can occur from shallow to deep waters (greater than 200 m).

With the aim of generating GARP models, DesktopGARP version 1.1.6 was used. One hundred binary models were generated for each species, with default parameters (0.01 convergence limit, 1000 maximum iterations, and allowing the use of atomic range, negated range and logit rules); thereafter models with more than 5% intrinsic omission (negative prediction of training localities) were eliminated (Phillips et al. 2004). According to the method described by Arriaga et al. 2004, the model with the highest Kappa score (which was used to determine whether test points fall into regions of predicted presence more often than expected by chance, given the proportion of map pixels predicted present by the model) was selected as the best map generated through GARP, for the species potential distribution for the region.

Maxent version 3.3.1 was used, and the iterative algorithm ran for 1000 rounds. The regularization parameter β was automatically set, and the logistic output format that gives an estimate of probability of presence was selected.

The potential distribution maps predicted with both programs were processed using ArcView 9.3 to generate the final maps, which include occurrences data points, hydrology, boundaries, and Region 11 delimitation.

Pathway Analysis

The methodology for the Pathways Analysis was adopted from that proposed by Aquatic Nuisance Species Task Force (ANSTF) and National Invasive Species Council (NISC) Prevention Committee via the Pathways Work Team (2007). This approach involves the following steps:

"First-Cut" Analysis—Multiple Pathways Triage and Threat Level Assessment

1. Copies of general pathway charts and listings were provided to all members of the working group.
2. Multiple Pathways of Interest were defined.
    a) The general inventory list and diagrams of all invasive species pathways were reviewed; any pathway that was not listed was added.
    b) All pathways that were pertinent to the study were selected and listed.

   c) Particular invasive species associated with each pathway were indicated.

3. Preliminary multi-pathway description.

   a) Once the "universe' of all potential pathways and the 'narrowed-down' list of pathways were complete, a preliminary or general description for each pathway was prepared. As a result a matrix was made.

4. Pathway threat level determination.

   a) According to the invasive species present in each pathway a threat level was assigned.
   b) Levels considered were: Human health, Economic health and Ecosystem health. The previous matrix was completed.

"Second-Cut" Analysis—Single Pathway Definition, Coupling with Inclusive Invasive Species Listing and Ecosystem Scope

1. Detailed Single Pathway Description.

   a) Based on the 'first-cut' analysis, a roughly prioritized list of pathways was obtained.
   b) For the purpose of the study we choose to define pathways in the simplest possible way, this is considering only the country of origin as the source (beginning point) and the Ecoregion as final destination (end point), with no intermediate places (mid points) as potential re-invasion sites.
   c) Pathways range was determined according to the ecosystems potentially invaded.

"Third-Cut" Analysis—Single Pathway Risk Analysis

1. The Risk Analysis was accomplished based on the following questionnaire considering varying degrees of uncertainty.

   - Question 1: What is the level of risk of this pathway introducing invasive species on a frequent basis?

   - Question 2: What is the level (0-5) of risk of this pathway transmitting a large number of different, viable invasive species?

   - Question 3: What is the level of risk (0-5) of this pathway transmitting a large number of viable individuals per invasive species?

   - Question 4: Based on the specific invasive species transmitted via this pathway, what is the relative level of risk (0-5) of this pathway introducing invasive species into hospitable ecosystems or habitats?

- Question 5: To what degree does the pathway's own ecosystem enhances the viability of, and the opportunity for, transmission of invasive species?
- Question 6: What is the level of risk (0-5) of this pathway introducing invasive species at multiple entry points?
- Question 7: What is the level of risk (0-5) of this pathway for transmitting invasive species, based on standard treatment measures? (Frame of Reference: Zero (0) level indicates all IS are dead upon arrival; 3 = most (60%) of the IS are still reproductively viable; 5 = 100% IS are alive, have expanded populations, colonies or enhanced invasiveness capabilities).
- Question 8: What is the level of risk of this pathway to assist spread of invasive species to uncontaminated shipments during transport or storage?
- Question 9: What is the level of risk (0-5) of this pathway for transmitting invasive species, based on current screening techniques? Or based on standard treatment measures?
- Question 10: What is the level of risk of the pathway transporting an invasive species that is difficult to detect once in the 'receiving point' ecosystem?
- Question 11: What is the level of risk of this pathway transmitting invasive species that are capable of surviving in multiple habitats (i.e., are generalists)?
- Question 12: What is the level of risk of this pathway transmitting invasive species into ecosystems conducive to natural spread?
- Question 13: What is the level of risk of this pathway transmitting invasive species that are further spread by human activities?
- Question 14: What is the level of risk (0-5) of the pathway introducing invasive species that are known to be invasive in similar ecosystems but are not yet present in the ecoregion?
- Question 15: What is the level of risk of this pathway transmitting invasive species that are novel and for which there is limited scientific data upon which to develop control methods?
- Question 16: What is the level of risk of this pathway transmitting an invasive species in which existing control options are too expensive to implement?

2. Based on prior analyses, the degree of invasiveness was assigned considering:
   a) impact category (i.e., human health, economy or ecosystem impact),
   b) pathway ecosystem scope (i.e., from local to international range) and
   pathway risk.

Figure 41. Categorization of Pathways and Sub-Pathways

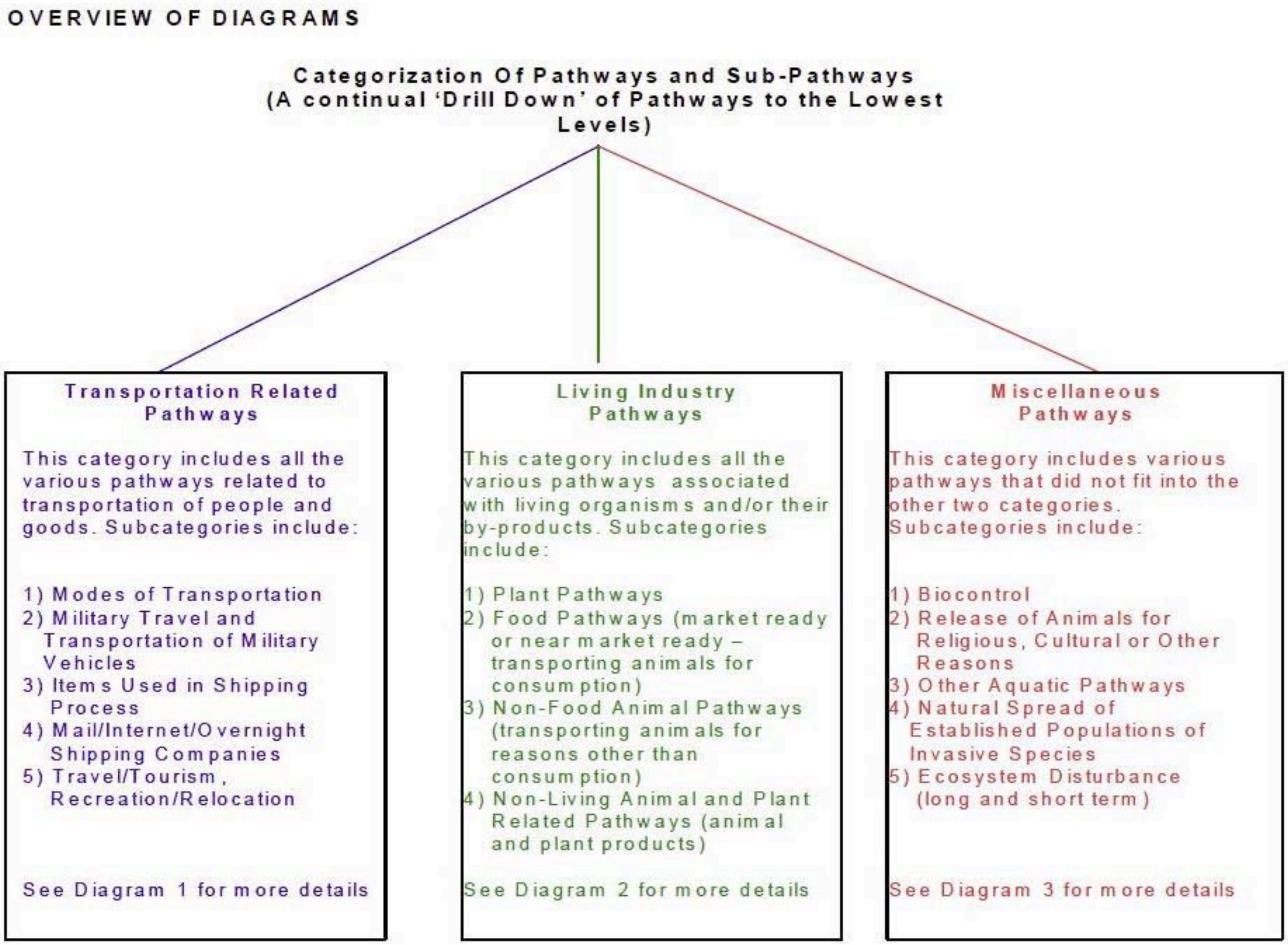


Figure 42. Transportation Related Pathways

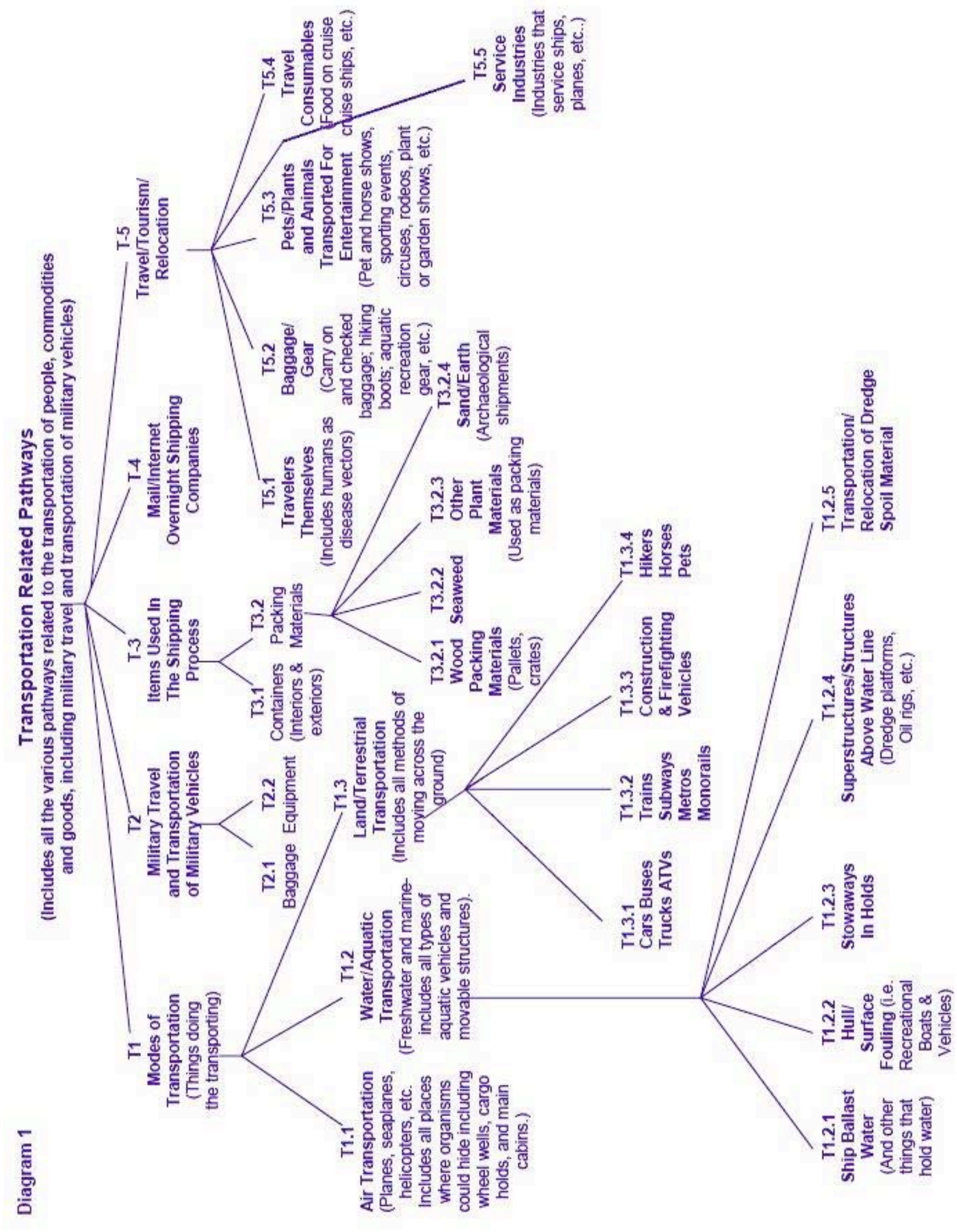


Figure 43. Living Industry Pathways

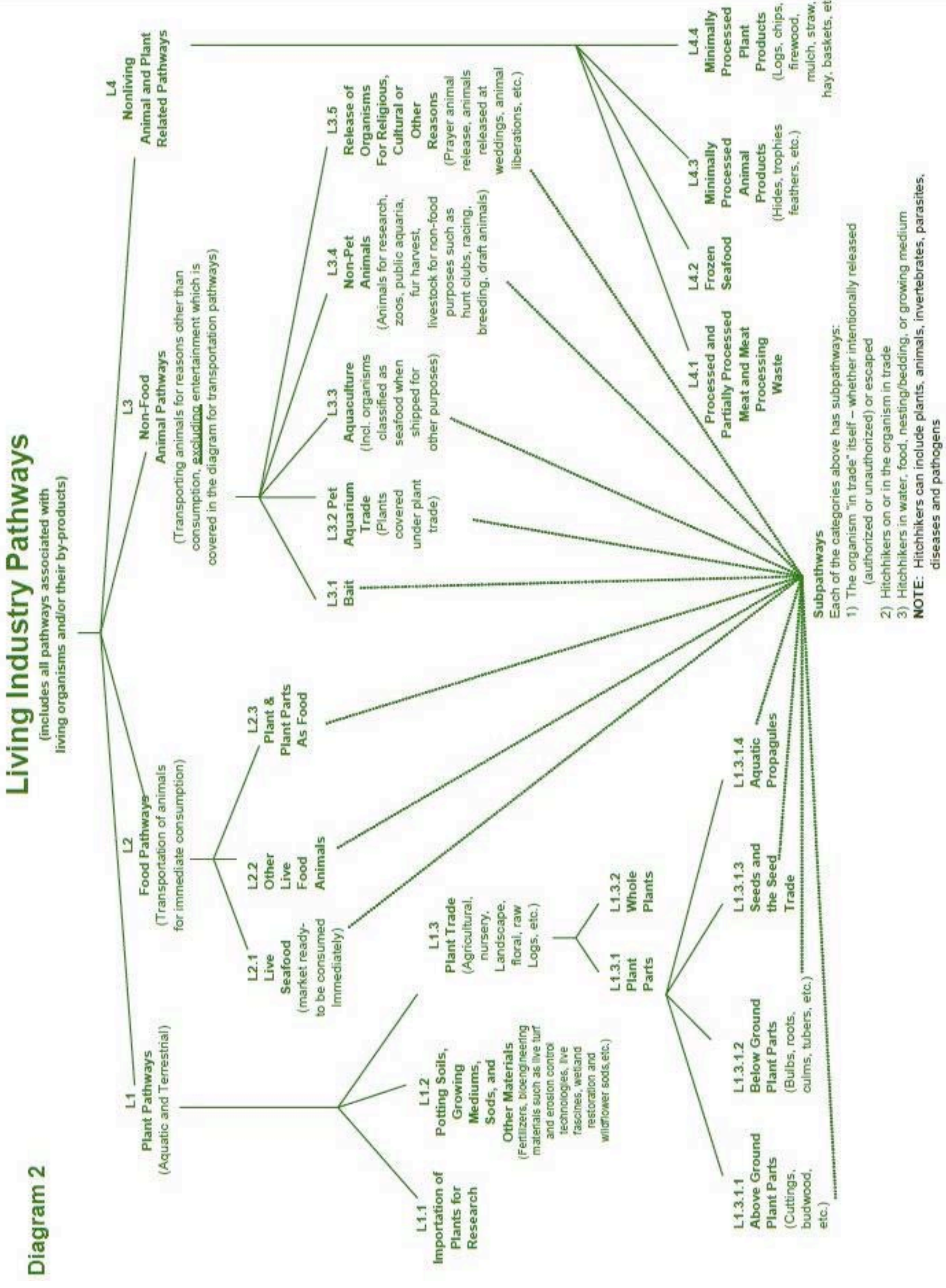
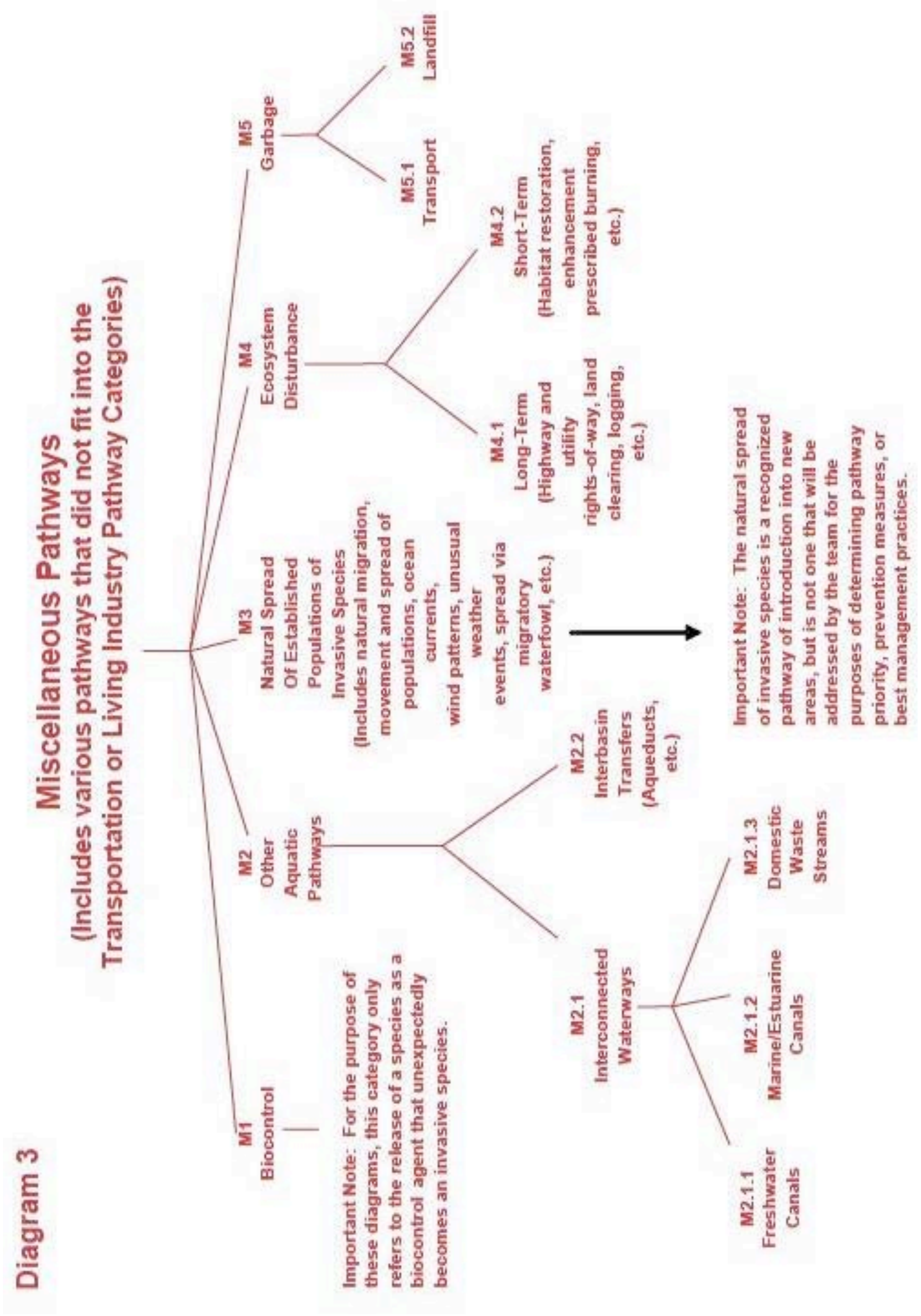


Figure 44. Miscellaneous Pathways



Species Invasiveness Evaluation

In order to characterize and assess the degree of invasiveness of the potential or known invasive species reported for Region 11, an algorithm for the *Species Invasiveness Score (SIS)* was developed, featuring a system of multivariable equations. The SIS for a species is calculated as follows:

The SIS for a species is calculated as follows:

$$\mathbf{SIS = IV + IGREV + SV + PV}$$

where:

$$\mathbf{IV = I_{H} + I_{Ec} + I_{En}}$$

$$\mathbf{IGREV = ((CECGR - CENR)/10 + PER)*20}$$

$$\mathbf{SV = IS - (CS + SR)/2}$$

$$\mathbf{PV = (P_{Sp} / P_{T})*20}$$

Explanation

The variables in the first equation are *Impact Value* (IV), *Invasive Geographical Range Extent Value* (IGREV), *Status Value* (SV), and *Pathway Value* (PV). They are summed to yield a value for the SIS (an SIS of the maximum value of 100 would indicate a highly invasive species, values close to zero will point to species of lower concern).

The supporting equations calculated as follows:

The term *Impact Value* (IV) has the highest value in the SIS equation, to a maximum value of 50, or half of the possible invasiveness score. The independent impacts are: *Impacts on Human Health* ($\mathbf{I_{H}}$**,** maximum value of 20), *Economic Impacts* ($\mathbf{I_{Ec}}$, maximum 15), and *Ecological/Environmental Impacts* ($\mathbf{I_{En}}$; including disease transmission among plants and animals, maximum 15).

The *Invasive Geographical Range Extent Value* (IGREV) has a maximum value of 20 and takes into account the difference between the *Continental Extent of Current Geographical Range* (CECGR) and the *Continental Extent Native Range* (CENR) in relation to the species' worldwide distribution. The maximum value would be assigned if a species native to one continent is reported as present on five continents (excluding Antarctica). For practical reasons, hybrid species are not considered native to any continent. To the difference between the current and the native range continents is added a value corresponding to their *Presence in the Ecological Region* (PER), which has values ranging from 0.6, if the species is present in the ecological region, to 0.3, when the species, despite not being reported in the ecological region, has been registered in neighboring states and thus represents a future threat, to zero when there are no reports of the species being present in the region.

The *Status Value* (SV) has a maximum value of 10 and is calculated from the independent variables, *Global Invasiveness Status* (IS), *Species Global Conservation Status* (CS), and *Species Status in the Ecological Region* (SR). The *Global Invasiveness Status* (IS) is assigned a value of 10 if the species is listed among the IUCN World's 100 Worst Invasive Alien Species; 5, if it is not on this list but is registered in the Global Invasive Species Database (GISD); and zero, if the species is not listed in either of the above. The *Conservation Status* is based on the IUCN conservation categories, and values of 10 are assigned to critical species, 8 for endangered species, 6 for vulnerable species, and 4 for species of lower concern. The values for *Species Status in the Ecological Region* are assigned as follows: 10 for endemic species, 8 for native species, 6 for transplanted species, 4 for cryptogenic species and hybrids of native species and 0 for exotic and cosmopolitan species.

Finally, the *Pathway Value* (PV) has a maximum numerical value of 20. This value is the result of the number of pathways through which the species has been introduced in the ecological region (P_{Sp}) compared to the total number of pathways though which species of the same group have been introduced (P_T).

Once the SIS values were determined for each one of the 373 exotic species reported for the ecological region, the species were ranked according to their degree of invasiveness, this ranking was made by calculating the range of the quartiles according to the frequency distribution of the SIS values. In this way, species with SIS values greater than 46 were designed as critical invasive species (Critical SIS); those species with SIS values between 33 to 46 were classified as highly invasive species (High SIS); species with SIS values between 25 to 33 were classified as moderately invasive (Mid SIS); finally all the species with SIS values less than 25 points were classified as low invasive species (Low SIS).

Results

Total Species

According to several databases,[14] reports and scientific articles, there are 373 exotic species (100 plants, 85 invertebrates, 162 fishes, 10 amphibians, 4 reptiles 1 mammal and 1 fungus, 2 protozoa, 4 bacteria and 4 viruses) present or reported in states neighboring Region 11 (Fig. 45).

Plants

Non-indigenous plants are stressors of aquatic ecosystems. Many species can form large monocultures that alter the abundance and diversity of the native flora or disturb physical aspects such as water flow, light penetration and dissolved oxygen concentration. While not all introduced aquatic plants convey extreme impacts, the consequences of most introductions have yet to be understood. Fundamentally, the establishment of non-indigenous plants preempts habitat for native species. As new taxa are introduced and their range expands, specific knowledge of their distribution and potential range is imperative for resource management (Benson et al. 2004).

One hundred non-indigenous aquatic plant species representing fifty-four families are catalogued herein as present (98) or reported in neighboring states (2) and posing a future threat to the Rio Bravo/Laguna Madre ecological region. Among them are representatives from most of the continents: roughly half are native to Asia (30%) and Europe (19%). Species native to more than one continent, therefore, are represented as

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[14] These include: California Invasive Plant Council Home, http://www.cal-ipc.org; Global Biodiversity Information Facility, http://es.mirror.gbif.org/; Global Invasive Species Database, http://www.issg.org/database/; Invasive Plant Atlas of New England, http://nbii-nin.ciesin.columbia.edu/; NAS-Non-indigenous Aquatic Species, http://nas.er.usgs.gov/; Plants Database, http://plants.usda.gov/; United States Department of Agriculture, http://www.invasivespeciesinfo.gov/; Washington State Department of Ecology, http://www.ecy.wa.gov/; Center for Invasive Species and Ecosystem Health:, http://www.invasive.org/; Texas Invasive Plant and Pest Council, http://www.texasinvasives.org/; SeaLife Base, http://www.sealifebase.org; Center for Aquatic and Invasive Plants-University of Florida, IFAS, http://plants.ifas.ufl.edu/node/201; Flora of Zimbabwe, http://www.zimbabweflora.co.zw; Discover Life, http://www.discoverlife.org; National Exotic Marine and Estuarine Species, http://invasions.si.edu/nemesis.

such. Only 15% of the species are native to North America, with a slight majority of the marine, brackish water, or freshwater species originating from the Atlantic coast (52.25%), compared to the Pacific coast. When all the species of the American continent are considered (29%), they equal those from Asia in importance (Fig. 46).

Figure 45. Number of Exotic Species (by Group) Present in Region 11

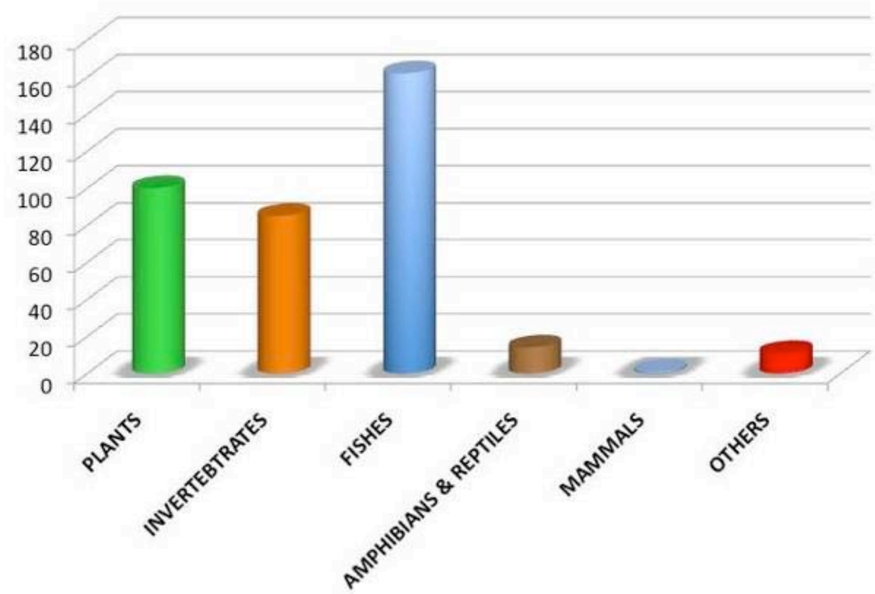
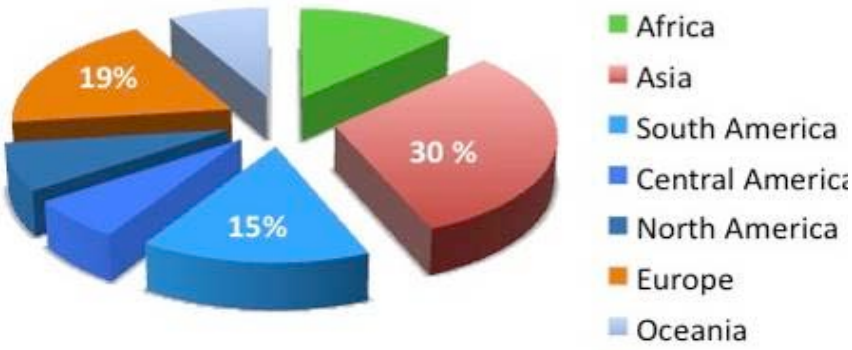


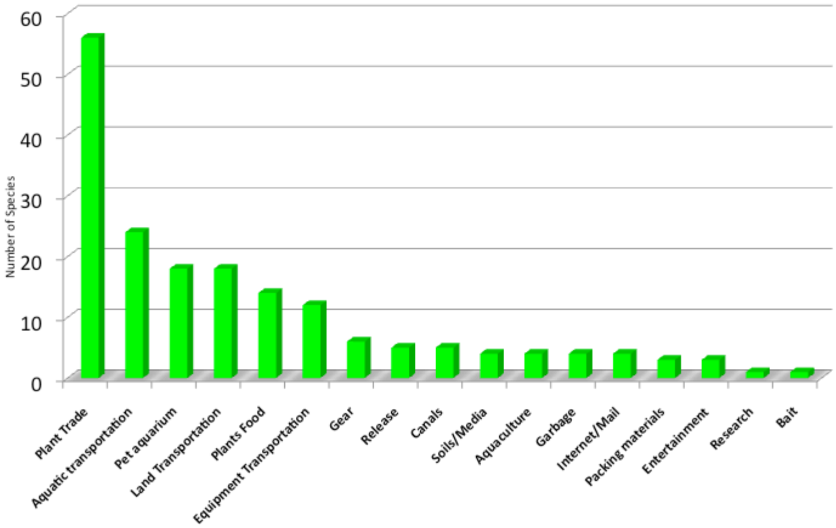
Figure 46. Source of Invasive Plants, by Continent



While some species appear to pose little threat to Region 11, others in the Region, like *Arundo donax*, *Eichhornia crassipes*, *Caulerpa taxifolia*, *Imperata cylindrica*, *Lythrum salicaria*, *Melaleuca quinquenervia*, *Mimosa pigra*, *Pueraria montana var. lobata*, *Schinus terebinthifolius*, are classified among the "One Hundred of the World's Worst Alien invasive Species" of the Global Invasive Species Database.

The main pathways associated to the presence of exotic plants in the Region 11 are plant trade (and its sub-pathways, i.e., whole plants, plant parts, etc.), aquatic transportation (including via dry ballast, hull surface, transportation of machinery equipment, etc.), pet-aquarium (plants sold for ornamental purposes in aquariums), and land transportation (Fig. 47).

Figure 47. Pathways Related to Invasive Plants Present in Region 11



When examining the relationship between the pathways and the source continent, it is evident that Asia is the main source in most of the pathways, followed by South America, particularly for important pathways such as bait and pet-aquarium trade. Although the role of Europe as a source continent is modest, it is constant, as it appears in most of the pathways and is especially relevant in some, including intentional release and aquatic transportation (Fig. 48).

Figure 48. Importance of Plant Pathways, by Source Region

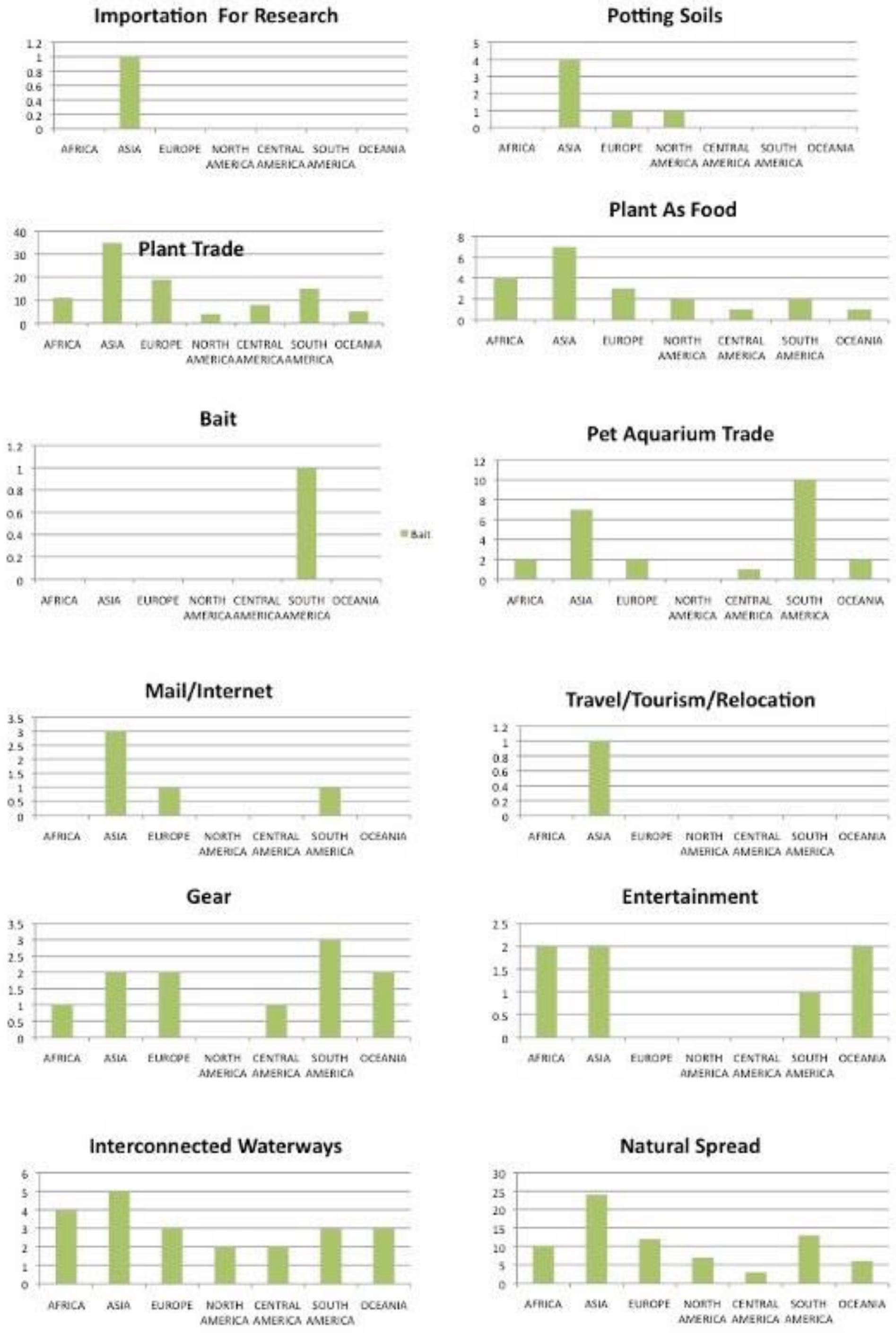
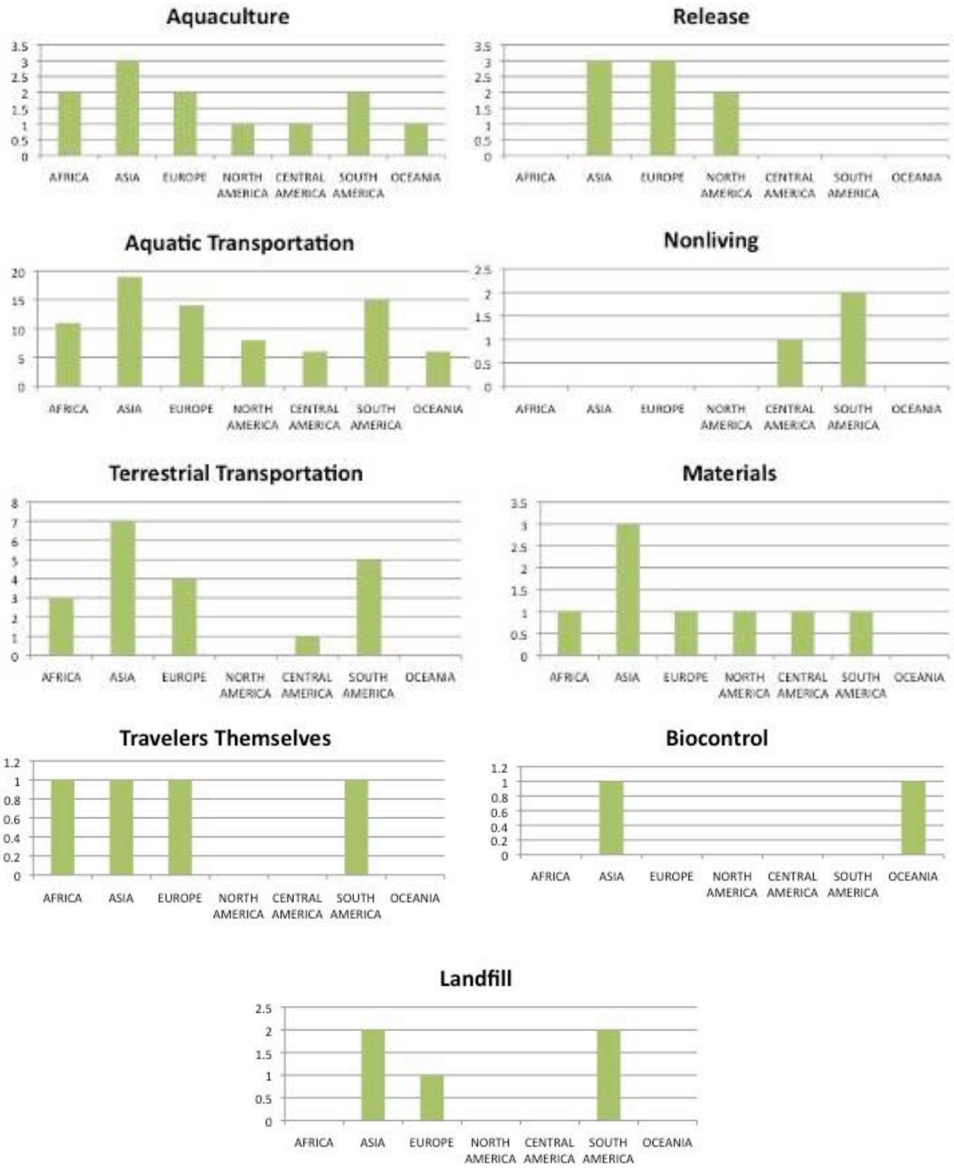
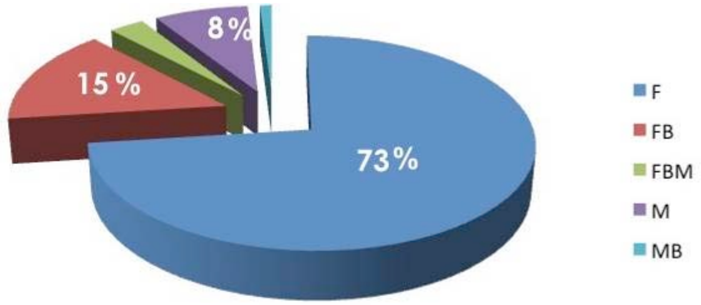


Figure 48. Importance of Plant Pathways, by Source Region *(cont.)*



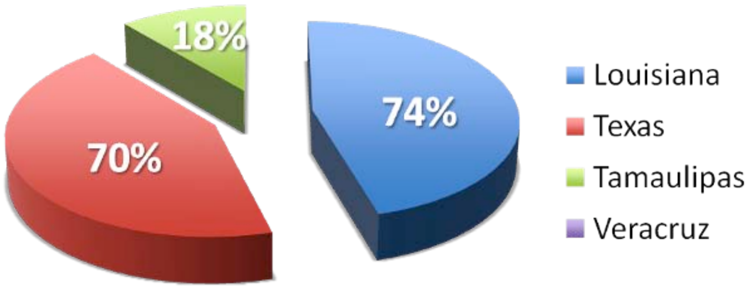
Most of the plants present in the Region 11 are of freshwater origin, followed by those of freshwater and brackish water origin (Figure 49). The great majority of invasive plant species present in the US portion of the Laguna Madre are particularly prominent in Texas and Louisiana, but some are present in other states as well (Fig. 50).

Figure 49. Source of Invasive Plants, by Aquatic Environment



F= Freshwater, FB= Fresh and brackish water, FBM= Fresh, brackish and marine water, M= Marine water, MB= Marine and brackish water.

Figure 50. Presence of Exotic Species, by State



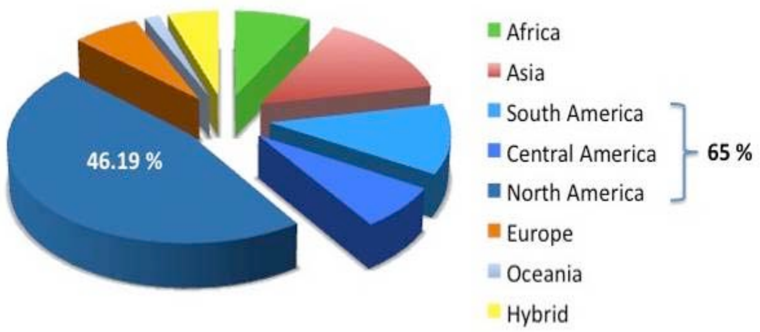
Percentages related to a total of 100 plants found.

Fishes

A total of 162 fish species have been introduced in the Region 11 or in neighboring states. Of these, the majority is from the Americas and almost half (46.19%) are native to North America. Most of these native transplants are from the Atlantic slope (91%). It is worth noting the presence of 10 fish hybrids, four of which are the product of the crossbreeding of native species (mainly game fish), while six are the result of crossings between exotic species (namely carps) (Fig. 51).

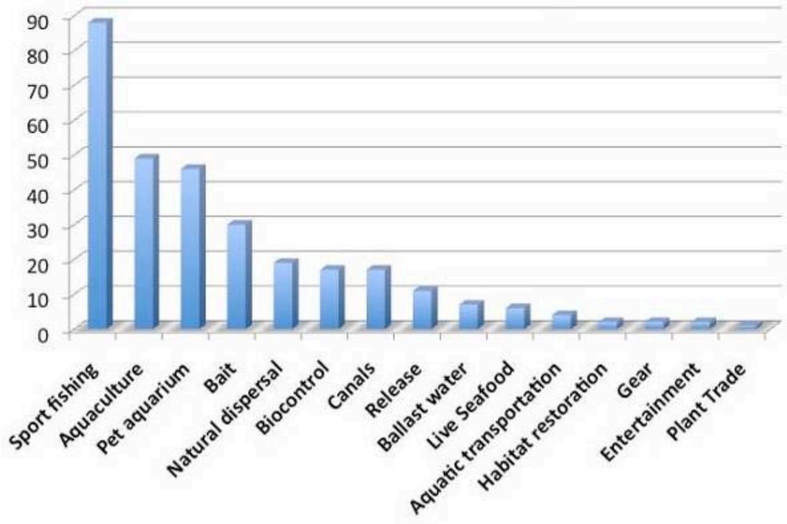
Several of these introduced fish (*Clarias batrachus*, *Cyprinus carpio*, *Gambusia affinis*, *Lates niloticus*, *Micropterus salmoides*, *Oncorhynchus mykiss*, *Oreochromis mossambicus*, and *Salmo trutta*) have been classified among the "One Hundred of the World's Worst Alien invasive Species" of the Global Invasive Species Database.

Figure 51. Source of Alien Invasive Fish, by Continent



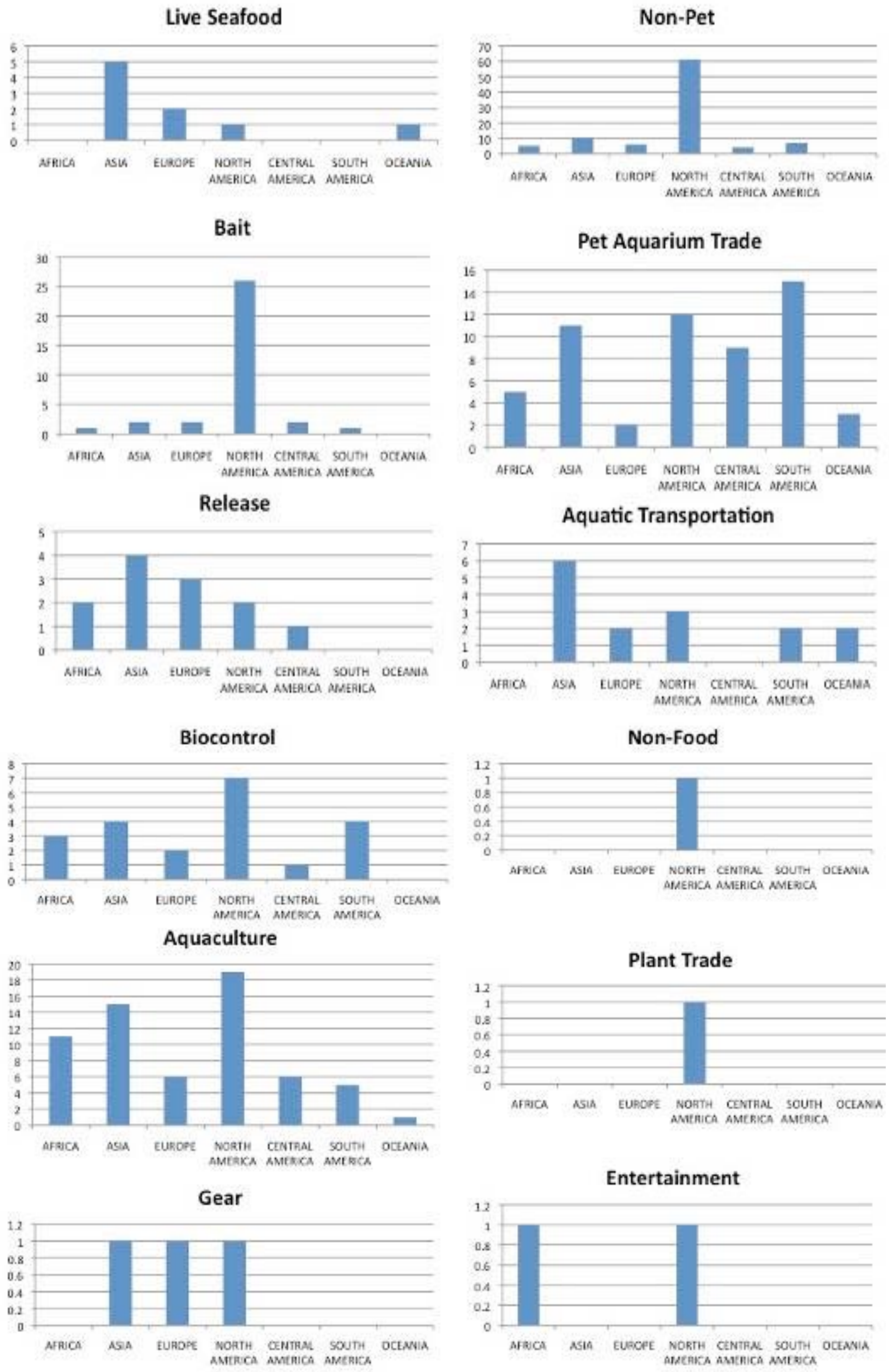
It is very clear that the major pathway for fish introductions to Region 11 is intentional stocking for sport fishing. Aquaculture and the pet-aquarium trade come next, and bait releases also contribute with some significant introductions. Fewer introductions are attributable to biocontrol, passage through canals, release of organisms for various purposes, ballast water, or live seafood (Fig. 52).

Figure 52. Pathways Related to Alien Invasive Fish Species Present in Region 11



The analysis of fish pathways by source continent reveals the important role of North America as a source region in most of the pathways. The non-pet (which includes stocking sport fish) and bait pathways are obviously related and both denote the significance of species from North America (e.g., *Morone saxatilis*, *Esox lucius*, *Cyprinella lutrensis* and *Astianax mexicanus*). On the other hand, Asia is an important participant in pathways such as live seafood, due to the cultural tradition of Asian communities in North America. Other important pathways like the pet-aquarium trade are represented by Asia and the Americas but, as expected, South America is a significant contributor as a source of many highly valued Amazonian fish (Fig. 53).

Figure 53. Importance of Fish Pathways, by Source



Live Seafood

Non-Pet

Bait

Pet Aquarium Trade

Release

Aquatic Transportation

Biocontrol

Non-Food

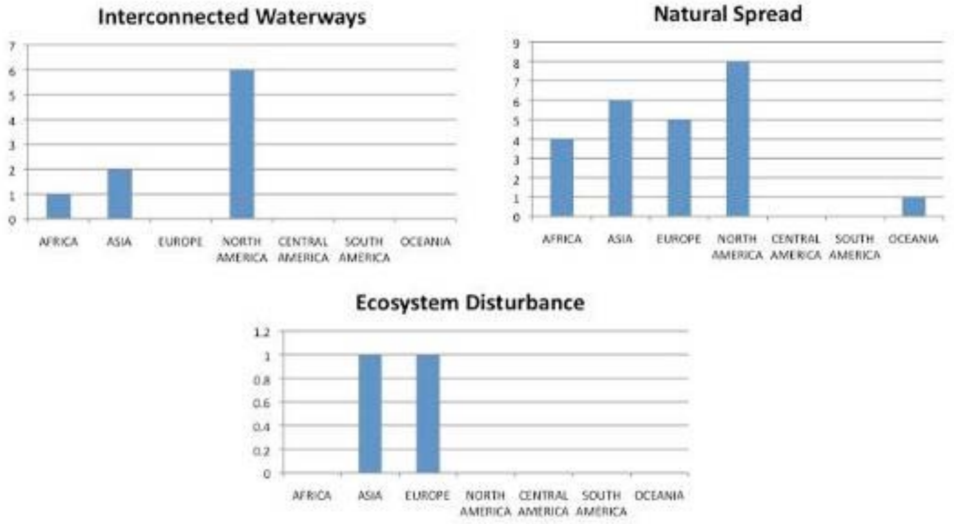
Aquaculture

Plant Trade

Gear

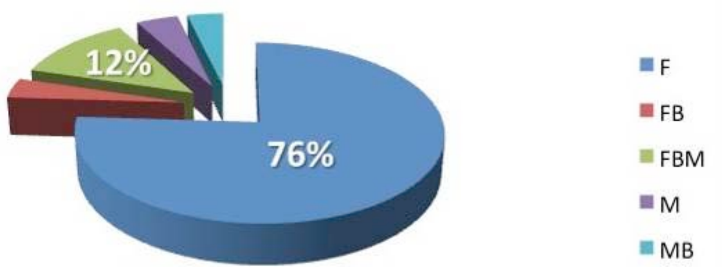
Entertainment

Figure 53. Importance of Fish Pathways, by Source *(cont.)*



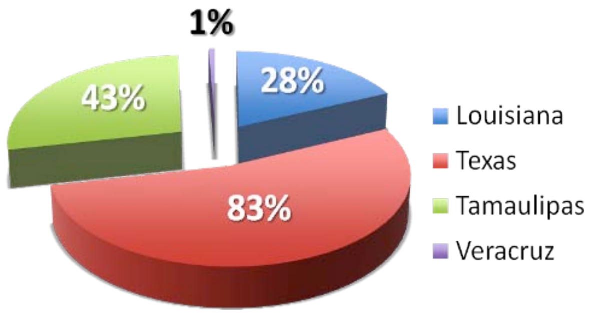
Most of these invasive fish are freshwater species, followed by fish thriving in brackish and marine environments (Fig. 54). Texas and California have the highest numbers of exotic fish in the United States (Fig. 55) (Fuller et al. 1999).

Figure 54. Source of fish, by aquatic environment



F= Freshwater, FB= Fresh and brackish water, FBM= Fresh, brackish and marine water, M= Marine water, MB= Marine and brackish water).

Figure 55. Presence of Exotic Species, by State



Percentages related to a total of 162 fishes found.

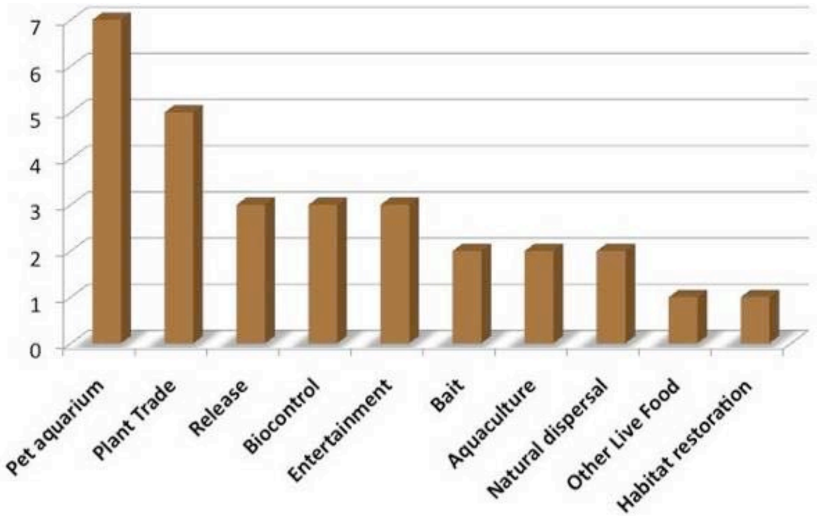
Amphibians and Reptiles

A combined total of 14 species of aquatic amphibians and reptiles have been introduced into Region 11 of which the great majority (86%) are native to North America, largely from the Atlantic slope (78.6%) (Fig. 56). This is in part a consequence of the high biodiversity of these groups on this continent. Some representatives of both groups (*Bufo marinus, Eleutherodactylus coqui, Lithobates catesbeianus* and *Trachemys scripta elegans*) are considered major threats and, as such, are classified among the "One Hundred of the World's Worst Alien Invasive Species" of the Global Invasive Species Database.

Figure 56. Source of Amphibians and Reptiles in Region 11

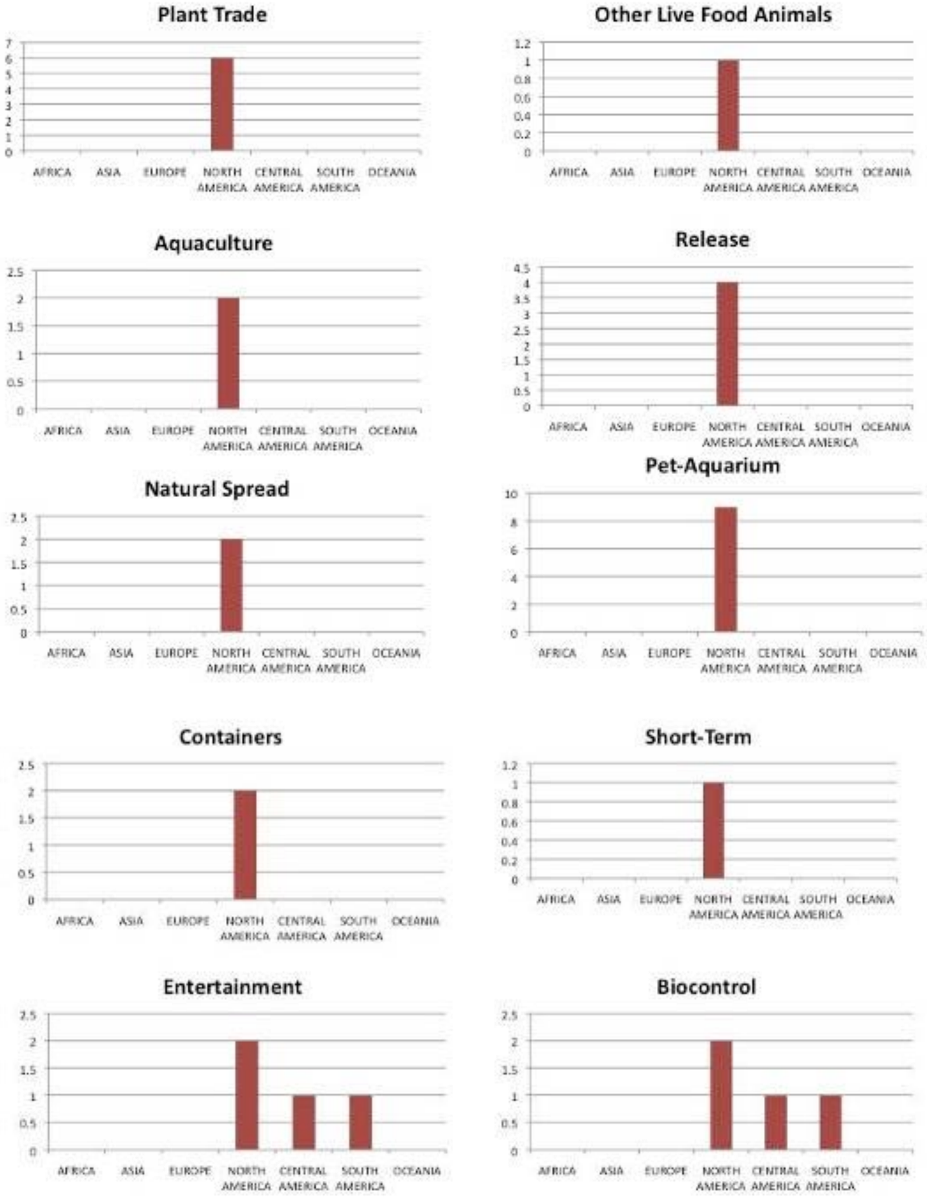
The most important pathway for the introduction of these groups is the pet-aquarium trade and, due to the species' natural ecological associations with plant species, the plant trade pathway follows in importance. Other minor pathways are also factors in the introductions of these groups, including release for various purposes, biocontrol, or entertainment (Fig. 57).

Figure 57. Pathways Related to Amphibian and Reptile Species Present in Region 11



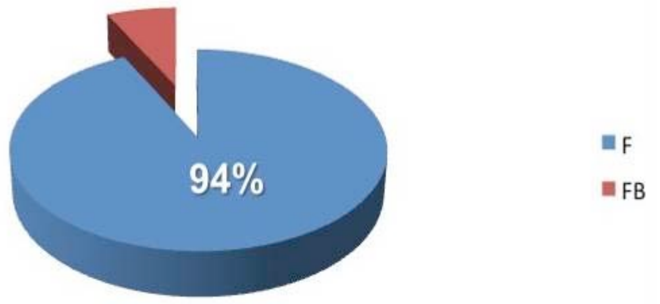
Because most of the species are native transplants, North America was the main source, via all pathways, of exotic species in Region 11 (Fig. 58).

Figure 58. Importance of Amphibian and Reptile Pathways, by Source Region



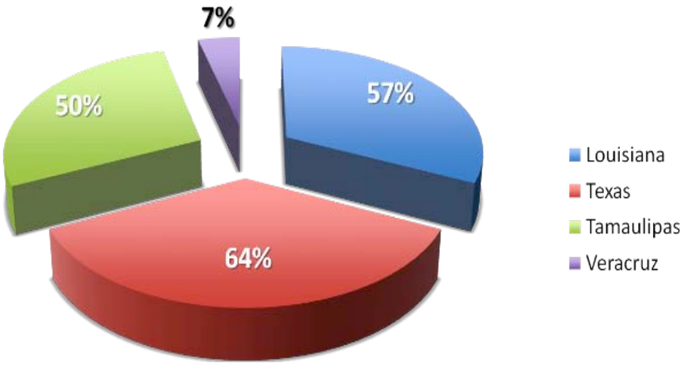
The great majority of invasive amphibians and reptiles are of freshwater origin and they are evenly distributed in all invaded areas (Texas Louisiana and Tamaulipas) (Figs. 59 and 60).

Figure 59. Source of Amphibians and Reptiles, by Aquatic Environment



F = Freshwater, FB = Fresh and brackish water.

Figure 60. Presence of Exotic Species, by State



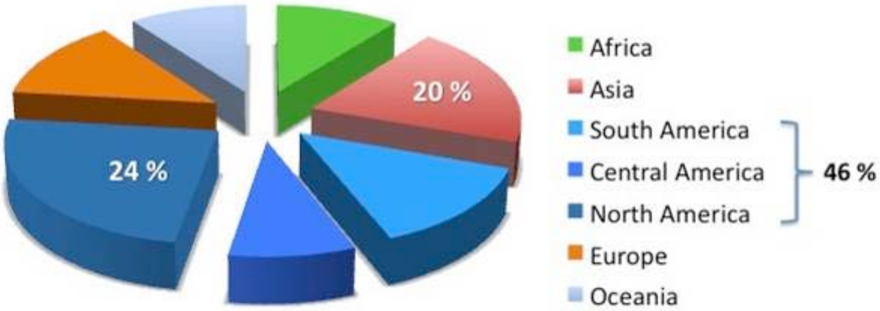
Percentages related to a total of 14 amphibians and reptiles found.

Invertebrates

Invasive invertebrate species present in Region 11 are native to all continents and, as with other groups, the main sources are the Americas (46%), particularly North America (Fig. 61). Some of these invertebrates (*Aedes albopictus*, *Carcinus maenas*, *Dreissena polymorpha*, *Eriocheir sinensis*, *Linepithema humile* and *Pomacea canaliculata*), characterized for posing important economic, environmental and health threats, are on the list of "One Hundred of the World’s Worst Alien invasive Species” of the Global Invasive Species Database.

The North American invasives are followed in number by species of Asian (20%) and South American (13%) origin. The majority (59.7%) of the native transplants came from the Atlantic slope and was introduced primarily by aquatic transportation and its sub-pathways (ballast water, hull fouling, etc.).

Figure 61. Source of Invertebrates, by Continent



Other important pathways associated with the introduction of invertebrates into Region 11 are aquaculture and the pet-aquarium trade (Figs. 62 and 63). This is the group for which natural dispersal is more important as a pathway.

Figure 62. Pathways Related to Invertebrate Species Present in Region 11

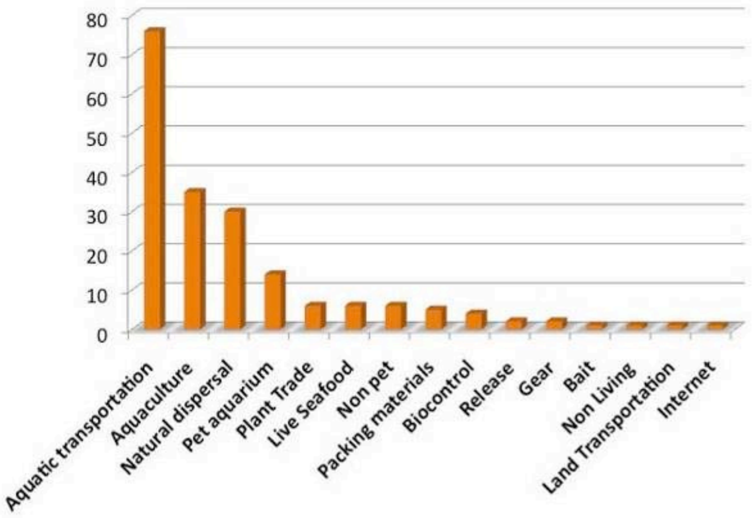


Figure 63. Importance of Invertebrate Pathways, by Source Region

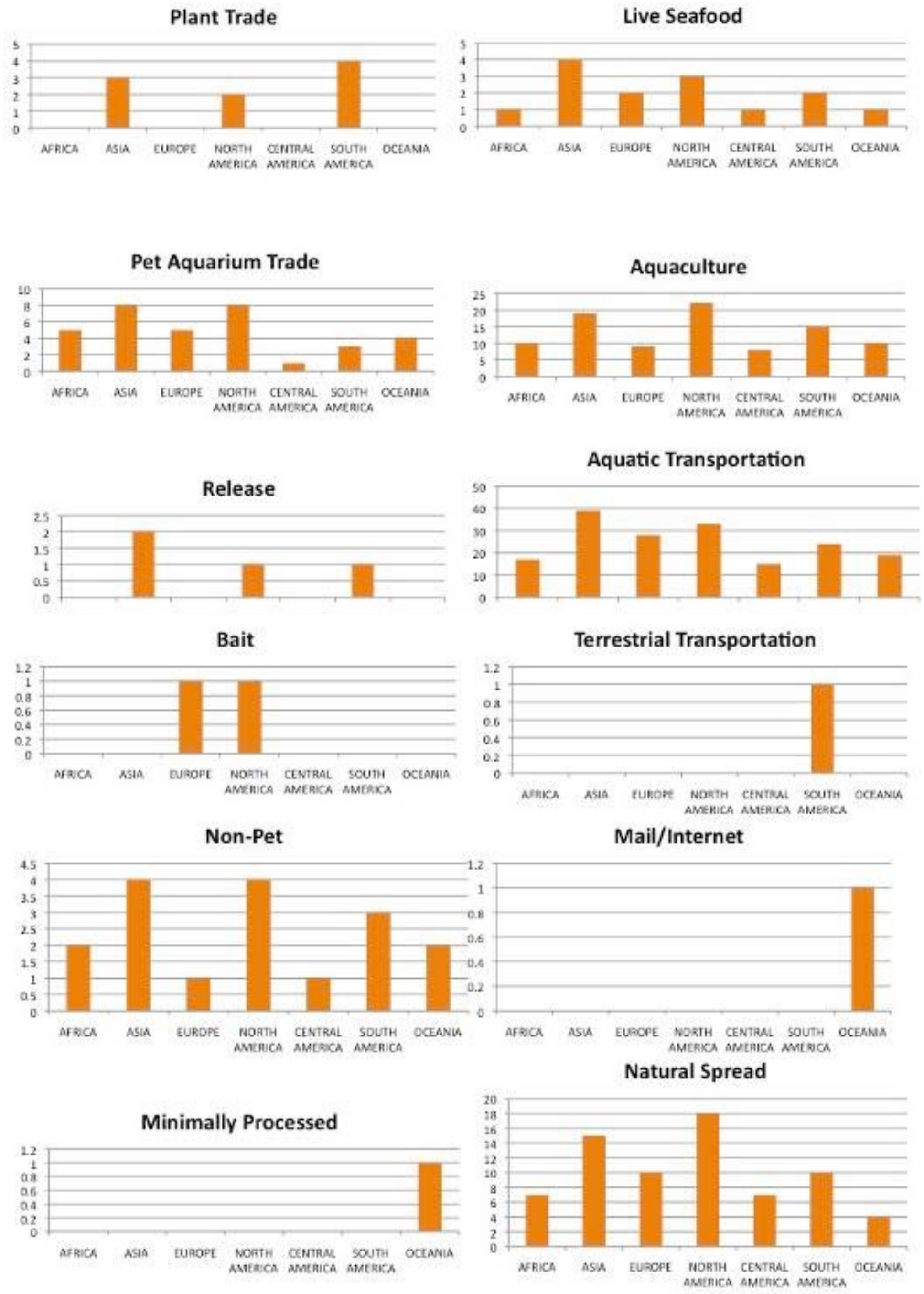
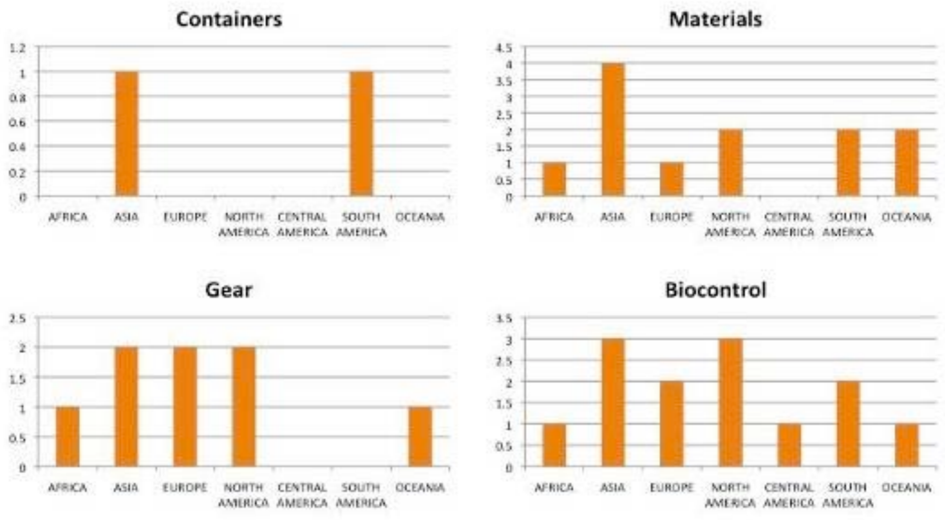
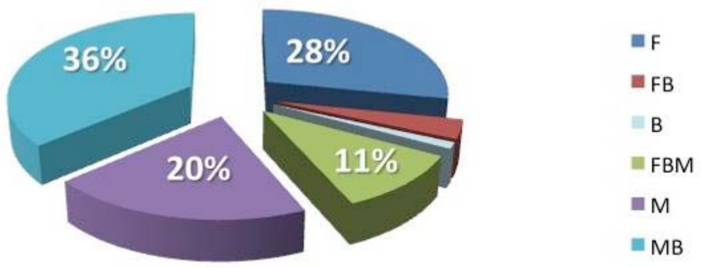


Figure 63. Importance of Invertebrate Pathways, by Source Region *(cont.)*



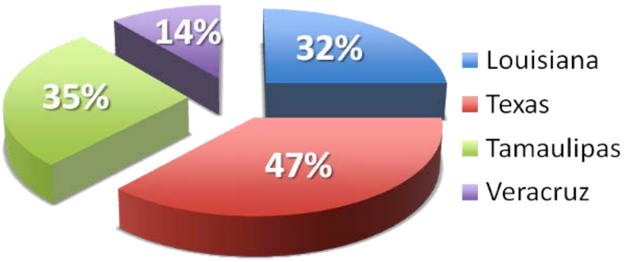
As for the role played by the aquatic environment itself, as opposed to the case with other species' groups, invertebrate introductions are only slightly more likely to come from marine and marine brackish environments than from freshwater sources (Figs. 64 and 65).

Figure 64. Source of Invertebrate Species, by Aquatic Environment



F= Freshwater, FB= Fresh and brackish water, FBM= Fresh, brackish and marine water, M= Marine water, MB= Marine and brackish water.

Figure 65. Presence of Exotic Species, by State

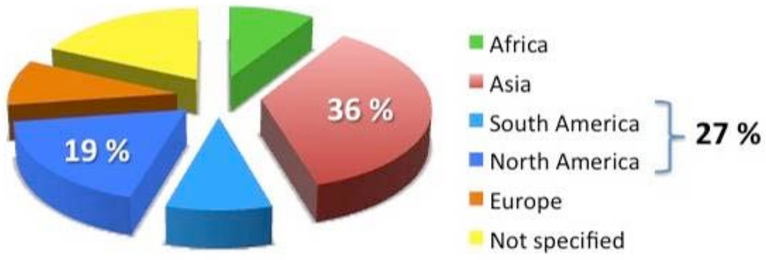


Percentages related to a total of 85 invertebrates found.

Others

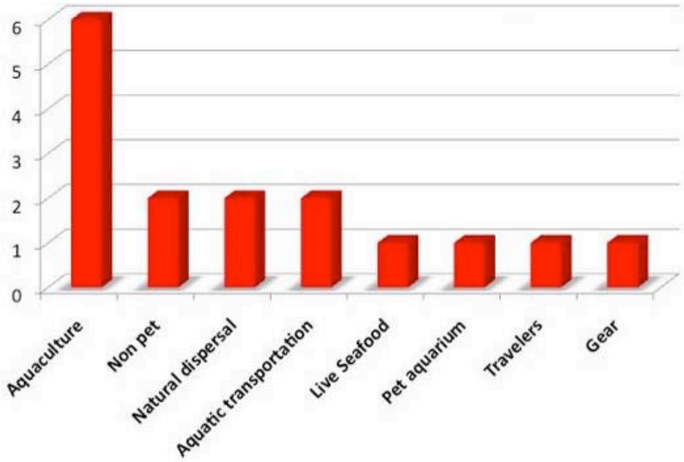
Microorganisms belonging to groups like bacteria and viruses fall within this category. These species originate from a relatively limited number of continents and regions and some of them are cosmopolitan, or their source is unknown. This is one of the few groups for which the American continent is not the main source as the majority of these species are native to Asia (Fig. 66). This group holds the most dangerous species in terms of economic and health damage (including impacts to human health). Nevertheless, none are considered to be among the "One Hundred of the World's Worst Alien Invasive Species" of the Global Invasive Species Database.

Figure 66. Source of Microorganisms, by Continent



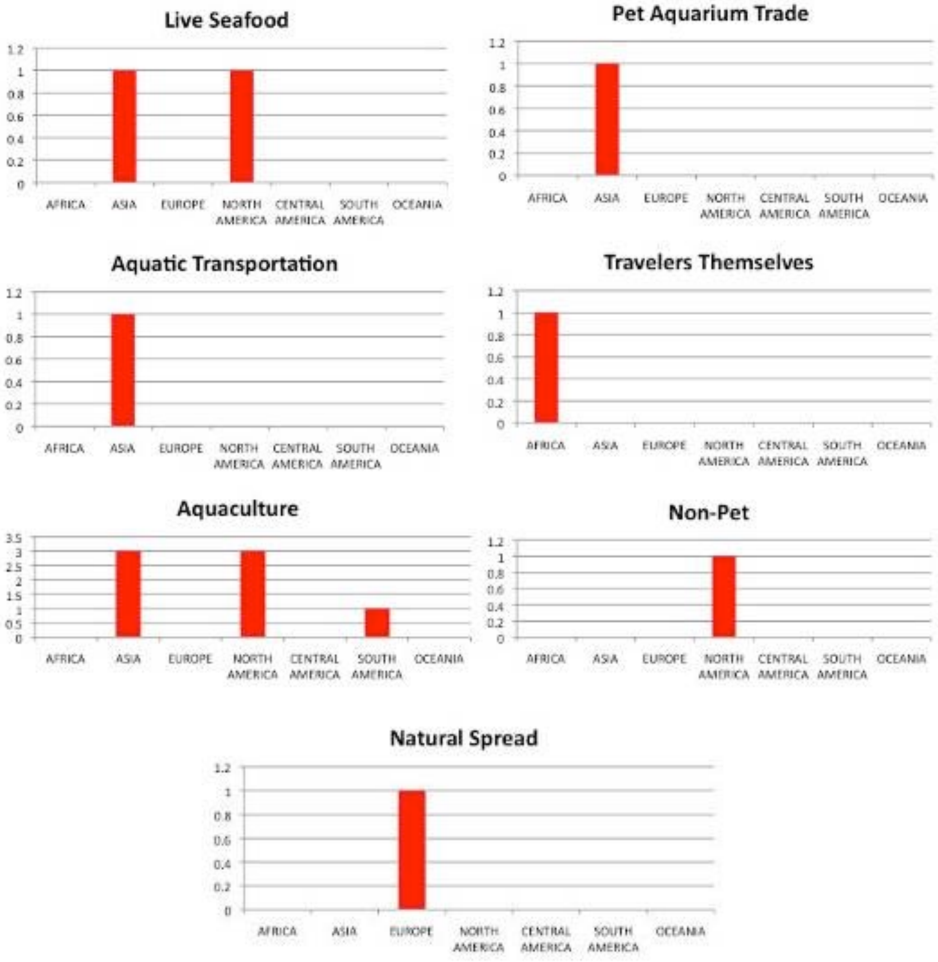
Aquaculture has been the most important pathway for introducing these groups into Region 11, due to the natural association of these species with their hosts (e.g., shrimp). The non-pet trade (animals for research, animals for non-food purposes, etc.) and aquatic transportation (chiefly via ballast water) pathways are also significant, together with their natural dispersal (Fig. 67).

Figure 67. Pathways Associated with the Introduction of Microorganisms to Region 11



The Asiatic origin of many of these species, can be corroborated in the aquatic transportation, aquaculture, live seafood and pet aquarium pathways. Others are continental translocations that arrived via aquaculture (Fig. 68).

Figure 68. Importance of Pathways for the Introduction of Microorganisms, by Source Region


Live Seafood

Pet Aquarium Trade

Aquatic Transportation

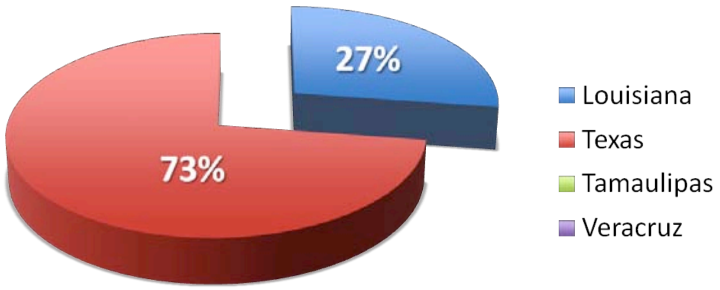
Travelers Themselves

Aquaculture

Non-Pet

Natural Spread

Figure 69. Presence of Exotic Species, by State



Percentages related to a total of 11 microorganisms found.

Mammals

There was only one aquatic exotic mammalian species present in all the states of Region 11, the nutria (*Myocastor coypus*). This freshwater species was associated with only one pathway: its natural dispersal.

Global

There is a close match between the sources of introduction in Region 11 and those for the Gulf of Mexico and the South Atlantic (Benson et al. 2001, Fuller 2005). In each case, North a stands as the main source, and the Americas altogether are the principal origin of the exotic species present in Region 11. Similarly, the continent of second-most importance for their origin is Asia (Figs. 70 and 71).

Figure 70. Origin by Continent/Region of All Taxa Present in Region 11 or Neighboring States

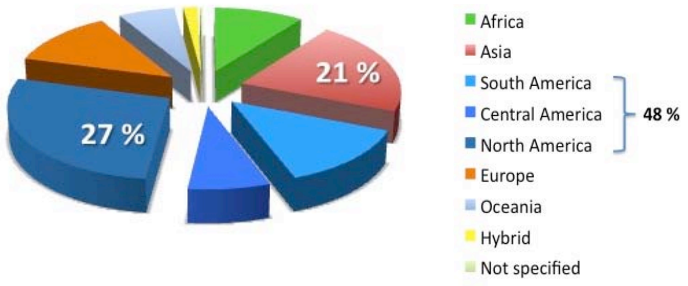
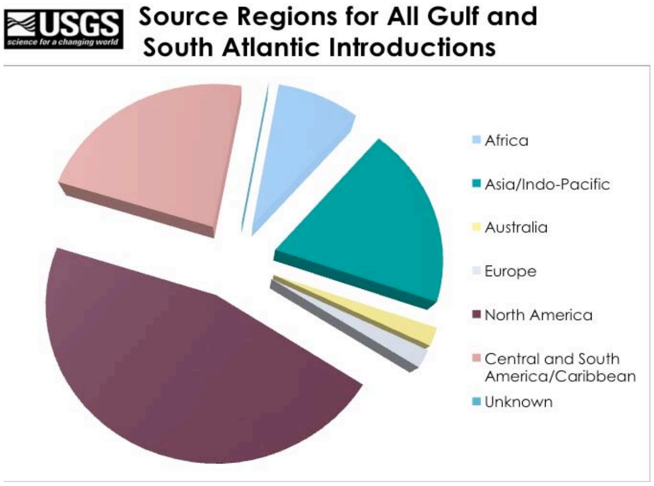


Figure 71. Origin by Continent/Region of Aquatic Exotic Species Present in the Gulf of Mexico and the South Atlantic



Source: Fuller, 2005.

There are also similarities in the pathways of introduction for all taxa. For example, stockage (classed under "non-pet" in this analysis) and the aquarium trade are two of the main pathways. A difference is that in Region 11, aquatic transportation (grouping ballast water, dry ballast, hull fouling, etc.) is much more important than in the Gulf of Mexico and the South Atlantic Region. Also, the aquaculture pathway plays a more important role in Region 11 than in the Gulf of Mexico and the South Atlantic (Figs. 72 and 73).

Figure 72. Importance of Pathways for All Taxa of Region 11

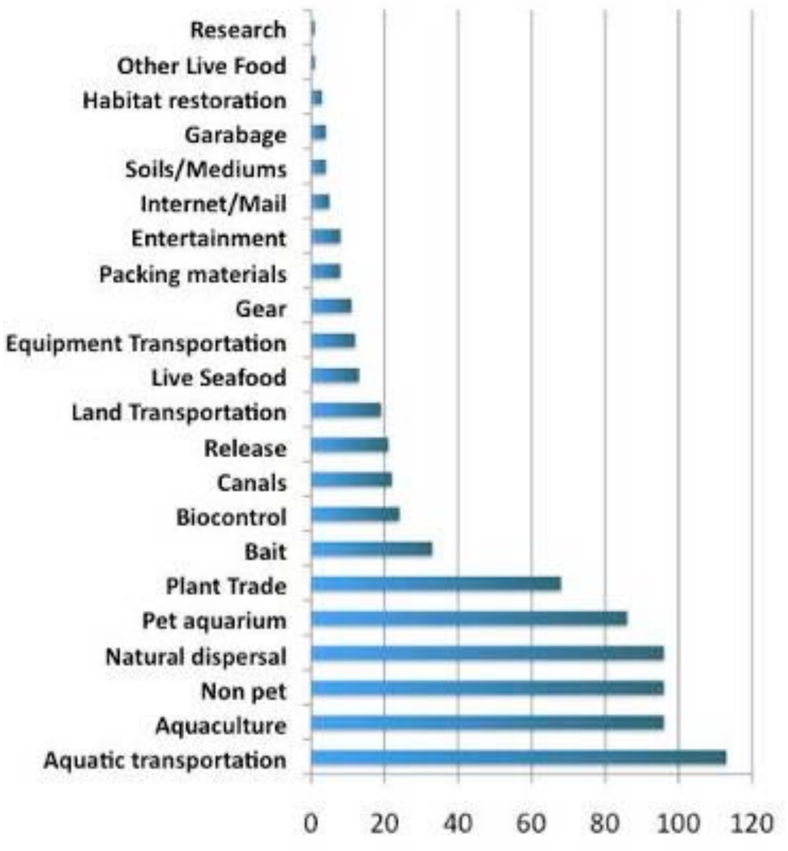
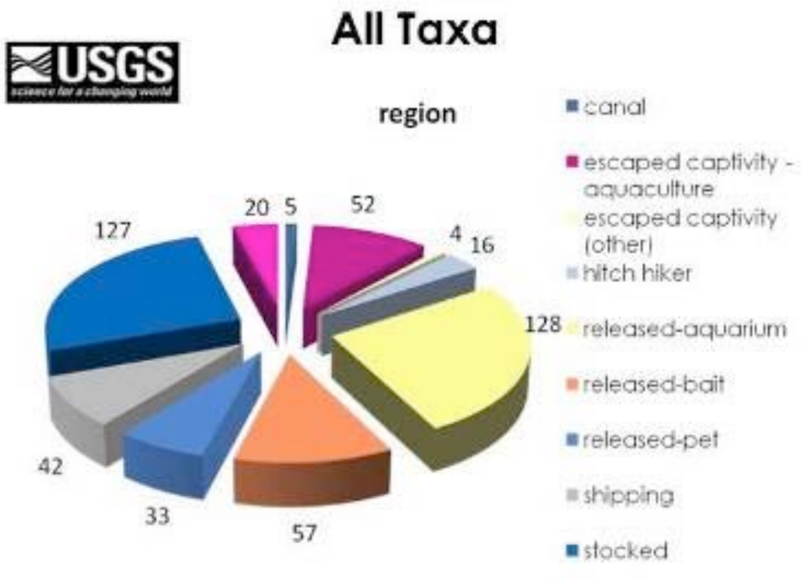
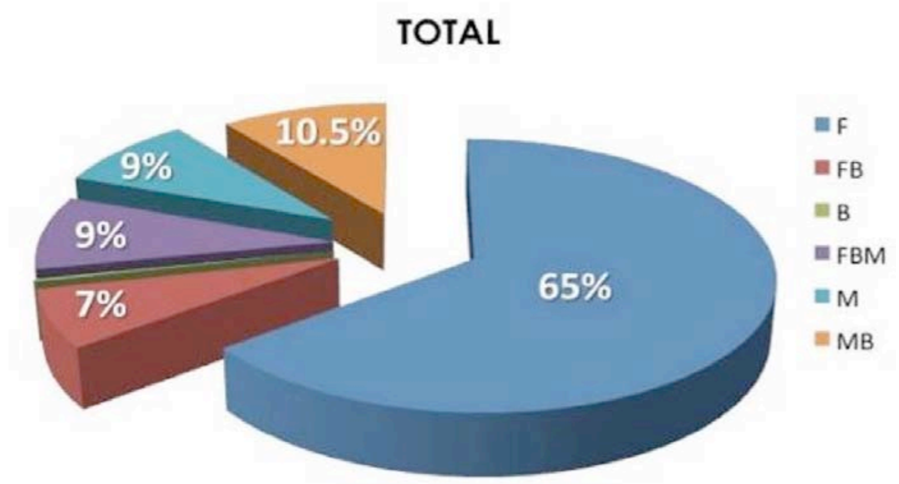


Figure 73. Importance of Pathways for All Taxa of the Gulf of Mexico and the South Atlantic



Most of the introductions in Region 11 are species from freshwater environments; however, when all the brackish-marine species are grouped, this environment is also seen as important (Fig. 74).

Figure 74. Total Number of Exotic Species, by Aquatic Environment



F = Freshwater, FB= Fresh and brackish water, FBM= Fresh, brackish and marine water, M= Marine water, MB= Marine and brackish water.

Critical SIS Species

According to the Species Invasiveness Score (SIS) index (Fig. 75), the maximum value registered for a species was 83 (for water hyacinth, *Eichhornia crassipes*) and the smallest value (of 2) was for the mollusk, *Tridacna maxima,* for which very little information was found. In relation to the ranking method, 94 species are scored as having critical impact (50 species of plants, 23 invertebrates, 15 fish, 2 amphibians, 1 reptile, 1 mammal, 1 bacteria and 1 virus). In addition, 28 of the 100 most invasive species, according to the IUCN, are found within the region, and the SIS showed that 21 of those rank as "critical" species for the region and 7 as "high impact species."

In the Tamaulipas Laguna Madre, 29 invasive species are found (4 are shared with Veracruz); of which 10 are among the IUCN's top 100. In the US portion, 65 species are found (either only in Texas, 46, or in Louisiana, 47, or in both states) that are not in Mexico, and 11 of those are in the IUCN's top 100.

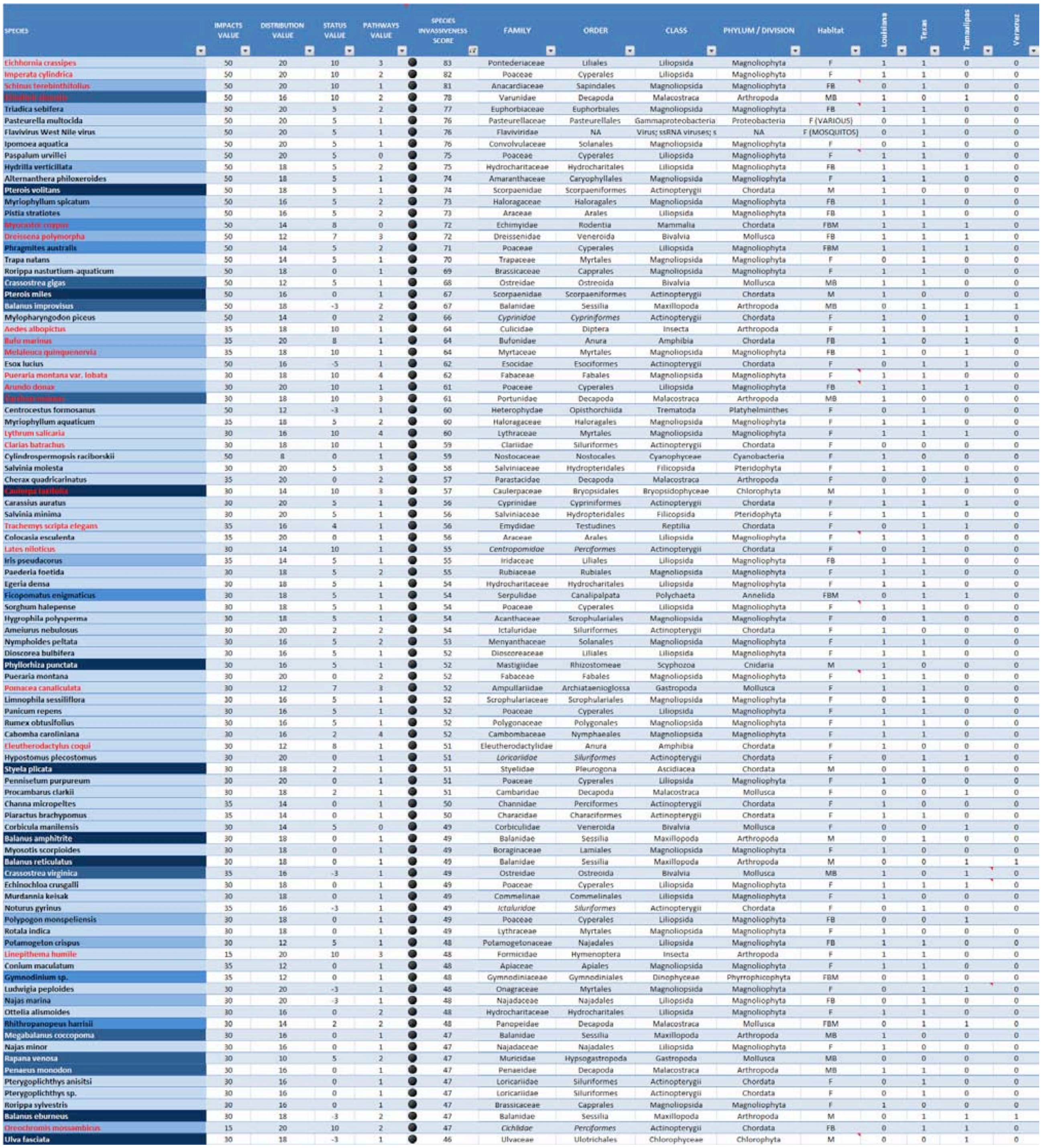
Results show that 58 of the critical impact species are from freshwater origin (11 of those are on the IUCN's top 100 list), 9 are marine species, 14 are found in both freshwater and brackish water, 8 inhabit marine and brackish environments and 5 can survive in all three. There are 15 species of fish listed as critical for the region, 2 marine species, 1 lives in brackish waters and the remaining 12 are freshwater species (Figs. 76 and 77).

There are 20 species of plants, 8 species of invertebrates, 7 species of fish, 1 amphibian, 1 reptile, 1 mammal and 2 microorganisms that pose a threat to human health in the Rio Bravo/Laguna Madre Region.

There is a close match between the total species entering through each pathway and the critical species. For the top 94 high impact species in the region, the most important pathway is aquatic transportation—ballast water and hull fouling (36 species) (Fig. 78). A further 28 species are imported via the aquarium trade, 26 through the plant trade and 19 through aquaculture. Whole plant commerce is the main pathway for plant introductions to the Rio Bravo-Laguna Madre region (8 species), followed by the pet-aquarium trade (4 species). Invertebrates are imported to the region mainly through aquaculture, the aquarium trade and hull surface fouling.

Aquarium trade, intentional fish stocking and aquaculture are the main pathways of introduction of fish species. Reptiles and amphibians come in through the aquarium trade, viruses enter through aquaculture, followed by ballast water and carried by non-pet animals.

Figure 75. Critical SIS Species Ranking



SPECIES	IMPACTS VALUE	DISTRIBUTION VALUE	STATUS VALUE	PATHWAYS VALUE		SPECIES INVASSIVENESS SCORE	FAMILY	ORDER	CLASS	PHYLUM / DIVISION	Habitat	Louisiana	Texas	Tamaulipas	Veracruz
Eichhornia crassipes	50	20	10	3	●	83	Pontederiaceae	Liliales	Liliopsida	Magnoliophyta	F	1	1	0	0
Imperata cylindrica	50	20	10	2	●	82	Poaceae	Cyperales	Liliopsida	Magnoliophyta	F	1	1	0	0
Schinus terebinthifolius	50	20	10	1	●	81	Anacardiaceae	Sapindales	Magnoliopsida	Magnoliophyta	FB	0	1	0	0
Eriocheir sinensis	50	16	10	2	●	78	Varunidae	Decapoda	Malacostraca	Arthropoda	MB	1	0	1	0
Triadica sebifera	50	20	5	2	●	77	Euphorbiaceae	Euphorbiales	Magnoliopsida	Magnoliophyta	FB	1	1	0	0
Pasteurella multocida	50	20	5	1	●	76	Pasteurellaceae	Pasteurellales	Gammaproteobacteria	Proteobacteria	F (VARIOUS)	0	1	0	0
Flavivirus West Nile virus	50	20	5	1	●	76	Flaviviridae	NA	Virus; ssRNA viruses; s	NA	F (MOSQUITOS)	0	1	0	0
Ipomoea aquatica	50	20	5	1	●	76	Convolvulaceae	Solanales	Magnoliopsida	Magnoliophyta	F	0	1	0	0
Paspalum urvillei	50	20	5	0	●	75	Poaceae	Cyperales	Liliopsida	Magnoliophyta	F	1	1	0	0
Hydrilla verticillata	50	18	5	2	●	75	Hydrocharitaceae	Hydrocharitales	Liliopsida	Magnoliophyta	FB	1	1	1	0
Alternanthera philoxeroides	50	18	5	1	●	74	Amaranthaceae	Caryophyllales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Pterois volitans	50	18	5	1	●	74	Scorpaenidae	Scorpaeniformes	Actinopterygii	Chordata	M	1	0	0	0
Myriophyllum spicatum	50	16	5	2	●	73	Haloragaceae	Haloragales	Magnoliopsida	Magnoliophyta	FB	1	1	0	0
Pistia stratiotes	50	16	5	2	●	73	Araceae	Arales	Liliopsida	Magnoliophyta	FB	1	1	0	0
Myocastor coypus	50	14	8	0	●	72	Echimyidae	Rodentia	Mammalia	Chordata	FBM	1	1	1	0
Dreissena polymorpha	50	12	7	3	●	72	Dreissenidae	Veneroida	Bivalvia	Mollusca	FB	1	1	1	0
Phragmites australis	50	14	5	2	●	71	Poaceae	Cyperales	Liliopsida	Magnoliophyta	FBM	1	1	1	0
Trapa natans	50	14	5	1	●	70	Trapaceae	Myrtales	Magnoliopsida	Magnoliophyta	F	0	1	0	0
Rorippa nasturtium-aquaticum	50	18	0	1	●	69	Brassicaceae	Capprales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Crassostrea gigas	50	12	5	1	●	68	Ostreidae	Ostreoida	Bivalvia	Mollusca	MB	1	1	0	0
Pterois miles	50	16	0	1	●	67	Scorpaenidae	Scorpaeniformes	Actinopterygii	Chordata	M	1	0	0	0
Balanus improvisus	50	18	-3	2	●	67	Balanidae	Sessilia	Maxillopoda	Arthropoda	MB	0	1	1	1
Mylopharyngodon piceus	50	14	0	2	●	66	*Cyprinidae*	*Cypriniformes*	Actinopterygii	Chordata	F	1	0	1	0
Aedes albopictus	35	18	10	1	●	64	Culicidae	Diptera	Insecta	Arthropoda	F	1	1	1	1
Bufo marinus	35	20	8	1	●	64	Bufonidae	Anura	Amphibia	Chordata	FB	1	0	1	0
Melaleuca quinquenervia	35	18	10	1	●	64	Myrtaceae	Myrtales	Magnoliopsida	Magnoliophyta	FB	1	0	1	0
Esox lucius	50	16	-5	1	●	62	Esocidae	Esociformes	Actinopterygii	Chordata	F	0	1	1	0
Pueraria montana var. lobata	30	18	10	4	●	62	Fabaceae	Fabales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Arundo donax	30	20	10	1	●	61	Poaceae	Cyperales	Liliopsida	Magnoliophyta	FB	1	1	1	0
Carcinus maenas	30	18	10	3	●	61	Portunidae	Decapoda	Malacostraca	Arthropoda	MB	1	0	0	0
Centrocestus formosanus	50	12	-3	1	●	60	Heterophydae	Opisthorchiida	Trematoda	Platyhelminthes	F	0	1	0	0
Myriophyllum aquaticum	35	18	5	2	●	60	Haloragaceae	Haloragales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Lythrum salicaria	30	16	10	4	●	60	Lythraceae	Myrtales	Magnoliopsida	Magnoliophyta	F	1	1	1	0
Clarias batrachus	30	18	10	1	●	59	Clariidae	Siluriformes	Actinopterygii	Chordata	F	0	0	0	0
Cylindrospermopsis raciborskii	50	8	0	1	●	59	Nostocaceae	Nostocales	Cyanophyceae	Cyanobacteria	F	1	0	0	0
Salvinia molesta	30	20	5	3	●	58	Salviniaceae	Hydropteridales	Filicopsida	Pteridophyta	F	1	1	0	0
Cherax quadricarinatus	35	20	0	2	●	57	Parastacidae	Decapoda	Malacostraca	Arthropoda	F	0	0	1	0
Caulerpa taxifolia	30	14	10	3	●	57	Caulerpaceae	Bryopsidales	Bryopsidophyceae	Chlorophyta	M	1	1	0	0
Carassius auratus	30	20	5	1	●	56	Cyprinidae	Cypriniformes	Actinopterygii	Chordata	F	1	1	1	0
Salvinia minima	30	20	5	1	●	56	Salviniaceae	Hydropteridales	Filicopsida	Pteridophyta	F	1	1	0	0
Trachemys scripta elegans	35	16	4	1	●	56	Emydidae	Testudines	Reptilia	Chordata	F	0	1	1	0
Colocasia esculenta	35	20	0	1	●	56	Araceae	Arales	Liliopsida	Magnoliophyta	F	1	1	0	0
Lates niloticus	30	14	10	1	●	55	*Centropomidae*	*Perciformes*	Actinopterygii	Chordata	F	0	1	0	0
Iris pseudacorus	35	14	5	1	●	55	Iridaceae	Liliales	Liliopsida	Magnoliophyta	FB	1	1	0	0
Paederia foetida	30	18	5	2	●	55	Rubiaceae	Rubiales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Egeria densa	30	18	5	1	●	54	Hydrocharitaceae	Hydrocharitales	Liliopsida	Magnoliophyta	F	1	1	0	0
Ficopomatus enigmaticus	30	18	5	1	●	54	Serpulidae	Canalipalpata	Polychaeta	Annelida	FBM	0	1	1	0
Sorghum halepense	30	18	5	1	●	54	Poaceae	Cyperales	Liliopsida	Magnoliophyta	F	1	1	0	0
Hygrophila polysperma	30	18	5	1	●	54	Acanthaceae	Scrophulariales	Magnoliopsida	Magnoliophyta	F	0	1	0	0
Ameiurus nebulosus	30	20	2	2	●	54	Ictaluridae	Siluriformes	Actinopterygii	Chordata	F	1	0	0	0
Nymphoides peltata	30	16	5	2	●	53	Menyanthaceae	Solanales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Dioscorea bulbifera	30	16	5	1	●	52	Dioscoreaceae	Liliales	Liliopsida	Magnoliophyta	F	1	1	0	0
Phyllorhiza punctata	30	16	5	1	●	52	Mastigiidae	Rhizostomeae	Scyphozoa	Cnidaria	M	1	0	0	0
Pueraria montana	30	20	0	2	●	52	Fabaceae	Fabales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Pomacea canaliculata	30	12	7	3	●	52	Ampullariidae	Archiataenioglossa	Gastropoda	Mollusca	F	1	1	0	0
Limnophila sessiliflora	30	16	5	1	●	52	Scrophulariaceae	Scrophulariales	Magnoliopsida	Magnoliophyta	F	0	1	0	0
Panicum repens	30	16	5	1	●	52	Poaceae	Cyperales	Liliopsida	Magnoliophyta	F	1	1	0	0
Rumex obtusifolius	30	16	5	1	●	52	Polygonaceae	Polygonales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Cabomba caroliniana	30	16	2	4	●	52	Cambombaceae	Nymphaeales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Eleutherodactylus coqui	30	12	8	1	●	51	Eleutherodactylidae	Anura	Amphibia	Chordata	F	1	0	0	0
Hypostomus plecostomus	30	20	0	1	●	51	*Loricariidae*	*Siluriformes*	Actinopterygii	Chordata	F	0	1	1	0
Styela plicata	30	18	2	1	●	51	Styelidae	Pleurogona	Ascidiacea	Chordata	M	0	1	0	0
Pennisetum purpureum	30	20	0	1	●	51	Poaceae	Cyperales	Liliopsida	Magnoliophyta	F	1	0	0	0
Procambarus clarkii	30	18	2	1	●	51	Cambaridae	Decapoda	Malacostraca	Mollusca	F	0	0	1	0
Channa micropeltes	35	14	0	1	●	50	Channidae	Perciformes	Actinopterygii	Chordata	F	1	0	0	0
Piaractus brachypomus	35	14	0	1	●	50	Characidae	Characiformes	Actinopterygii	Chordata	F	1	1	0	0
Corbicula manilensis	30	14	5	0	●	49	Corbiculidae	Veneroida	Bivalvia	Mollusca	F	0	0	1	0
Balanus amphitrite	30	18	0	1	●	49	Balanidae	Sessilia	Maxillopoda	Arthropoda	M	0	1	0	0
Myosotis scorpioides	30	18	0	1	●	49	Boraginaceae	Lamiales	Magnoliopsida	Magnoliophyta	F	1	0	0	0
Balanus reticulatus	30	18	0	1	●	49	Balanidae	Sessilia	Maxillopoda	Arthropoda	M	0	0	1	1
Crassostrea virginica	35	16	-3	1	●	49	Ostreidae	Ostreoida	Bivalvia	Mollusca	MB	1	0	1	0
Echinochloa crusgalli	30	18	0	1	●	49	Poaceae	Cyperales	Liliopsida	Magnoliophyta	F	1	1	1	0
Murdannia keisak	30	18	0	1	●	49	Commelinae	Commelinales	Liliopsida	Magnoliophyta	F	1	0	0	0
Noturus gyrinus	35	16	-3	1	●	49	*Ictaluridae*	*Siluriformes*	Actinopterygii	Chordata	F	0	1	0	0
Polypogon monspeliensis	30	18	0	1	●	49	Poaceae	Cyperales	Liliopsida	Magnoliophyta	FB	0	0	1	
Rotala indica	30	18	0	1	●	49	Lythraceae	Myrtales	Magnoliopsida	Magnoliophyta	F	1	0	0	0
Potamogeton crispus	30	12	5	1	●	48	Potamogetonaceae	Najadales	Liliopsida	Magnoliophyta	FB	1	1	0	0
Linepithema humile	15	20	10	3	●	48	Formicidae	Hymenoptera	Insecta	Arthropoda	F	1	1	0	0
Conium maculatum	35	12	0	1	●	48	Apiaceae	Apiales	Magnoliopsida	Magnoliophyta	F	1	1	0	0
Gymnodinium sp.	35	12	0	1	●	48	Gymnodiniaceae	Gymnodiniales	Dinophyceae	Phyrrophicophyta	FBM	0	1	0	0
Ludwigia peploides	30	20	-3	1	●	48	Onagraceae	Myrtales	Magnoliopsida	Magnoliophyta	F	0	1	1	0
Najas marina	30	20	-3	1	●	48	Najadaceae	Najadales	Liliopsida	Magnoliophyta	FB	0	1	0	0
Ottelia alismoides	30	16	0	2	●	48	Hydrocharitaceae	Hydrocharitales	Liliopsida	Magnoliophyta	F	1	1	0	0
Rhithropanopeus harrisii	30	14	2	2	●	48	Panopeidae	Decapoda	Malacostraca	Mollusca	FBM	0	1	1	0
Megabalanus coccopoma	30	16	0	1	●	47	Balanidae	Sessilia	Maxillopoda	Arthropoda	MB	1	0	0	0
Najas minor	30	16	0	1	●	47	Najadaceae	Najadales	Liliopsida	Magnoliophyta	F	1	0	0	0
Rapana venosa	30	10	5	2	●	47	Muricidae	Hypsogastropoda	Gastropoda	Mollusca	MB	0	0	0	0
Penaeus monodon	30	16	0	1	●	47	Penaeidae	Decapoda	Malacostraca	Arthropoda	MB	1	1	0	0
Pterygoplichthys anisitsi	30	16	0	1	●	47	Loricariidae	Siluriformes	Actinopterygii	Chordata	F	0	1	0	0
Pterygoplichthys sp.	30	16	0	1	●	47	Loricariidae	Siluriformes	Actinopterygii	Chordata	F	0	1	0	0
Rorippa sylvestris	30	16	0	1	●	47	Brassicaceae	Capprales	Magnoliopsida	Magnoliophyta	F	1	0	0	0
Balanus eburneus	30	18	-3	2	●	47	Balanidae	Sessilia	Maxillopoda	Arthropoda	M	0	1	1	1
Oreochromis mossambicus	15	20	10	2	●	47	*Cichlidae*	*Perciformes*	Actinopterygii	Chordata	FB	0	1	1	0
Ulva fasciata	30	18	-3	1	●	46	Ulvaceae	Ulotrichales	Chlorophyceae	Chlorophyta	M	0	0	1	0

Species names marked in red are those that appear in the Top 100 IUCN Invasive Species Listing.

Figure 76. Critical SIS Species by Habitat, and Top 100 IUCN Most Invasive Species

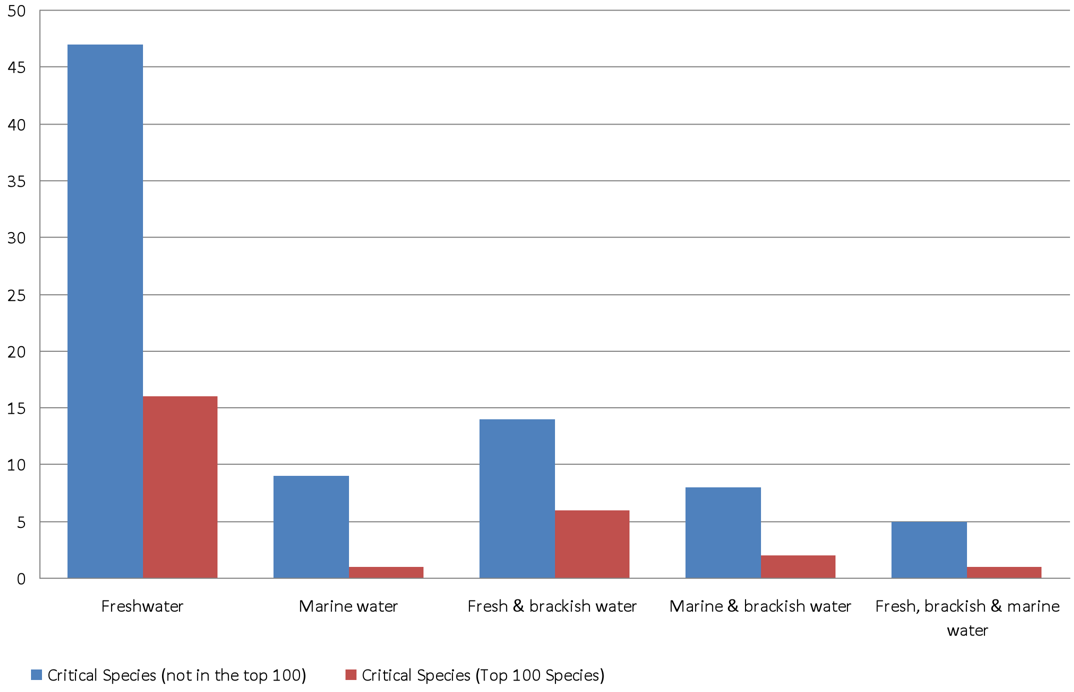
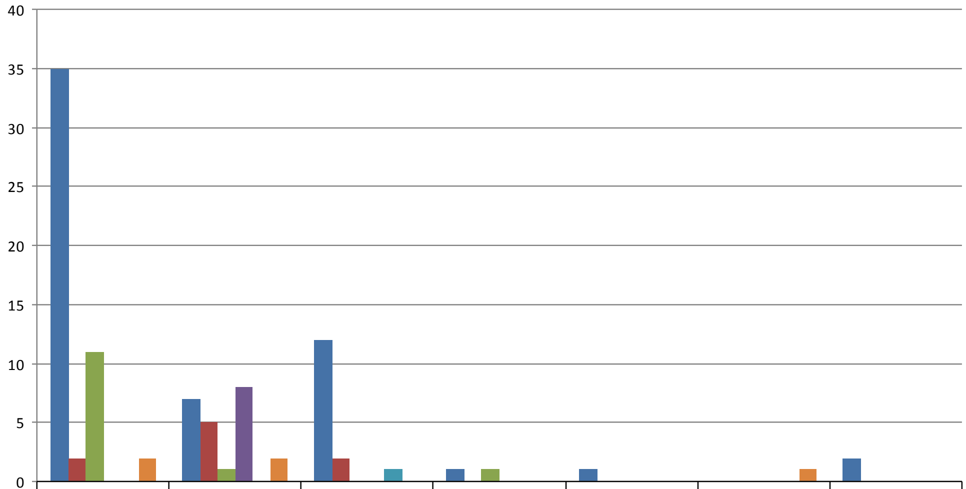
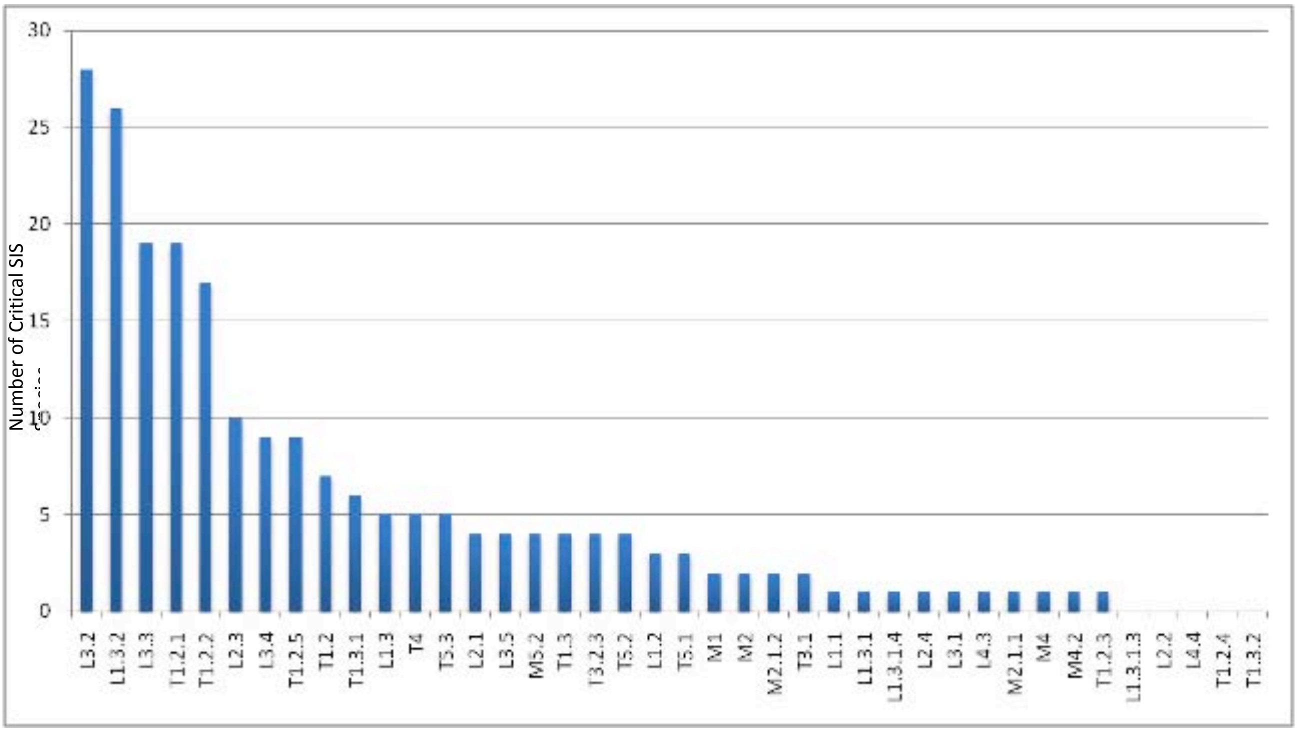


Figure 77. Critical SIS Species by Group and by Habitat



	Plants	Invertebrates	Fish	Amphibians	Reptiles	Mammals	Others
🟦 Freshwater	35	7	12	1	1	0	2
🟥 Marine water	2	5	2	0	0	0	0
🟩 Fresh & brackish watter	11	1	0	1	0	0	0
🟪 Marine & brackish water	0	8	0	0	0	0	0
■ Brackish water	0	0	1	0	0	0	0
🟧 Fresh, brackish & marine water	2	2	0	0	0	1	0

Figure 78. Importance of Pathways by Group of the Critical SIS Species



Pathways list:

(T) Transportation

T 1 Modes of Transportation
T1.1 Air
T1.2 Water/Aquatic
T1.2.1 Ship Ballast Water
T1.2.2 Hull/Surface Fouling (i.e., Recreational Boats and Vessels)
T1.2.3 Stowaways in Holds
T1.2.4 Superstructures/Structures Above Water Line
T1.2.5 Transportation/Relocation of Dredge Spoil Material
T1.3 Land Terrestrial
T1.3.1 Cars, Buses, Trucks, ATVs. Trailers for recreational boats
T1.3.2 Trains, Subways, Metros, Monorails
T1.3.3 Construction/Firefighting Vehicles
T1.3.4 Hikers, Horses Pets
T2 Military Travel and Transportation of Military Vehicles
T2.1 Baggage/Gear
T2.2 Equipment
T3 Items used in the Shipping Process
T3.1 Containers
T3.2 Packing Materials
T3.2.1 Wood Packing Materials
T3.2.2 Seaweed
T3.2.3 Other Plant Materials
T3.2.4 Sand/Earth
T4 Mail/Internet Overnight shipping
T5 Travel Tourism/Relocation
T5.1 Travelers Themselves
T5.2 Baggage/Gear
T5.3 Pets/Plants and Animals Transported for Entertainment
T5.4 Travel Consumables
T5.5 Service Industries

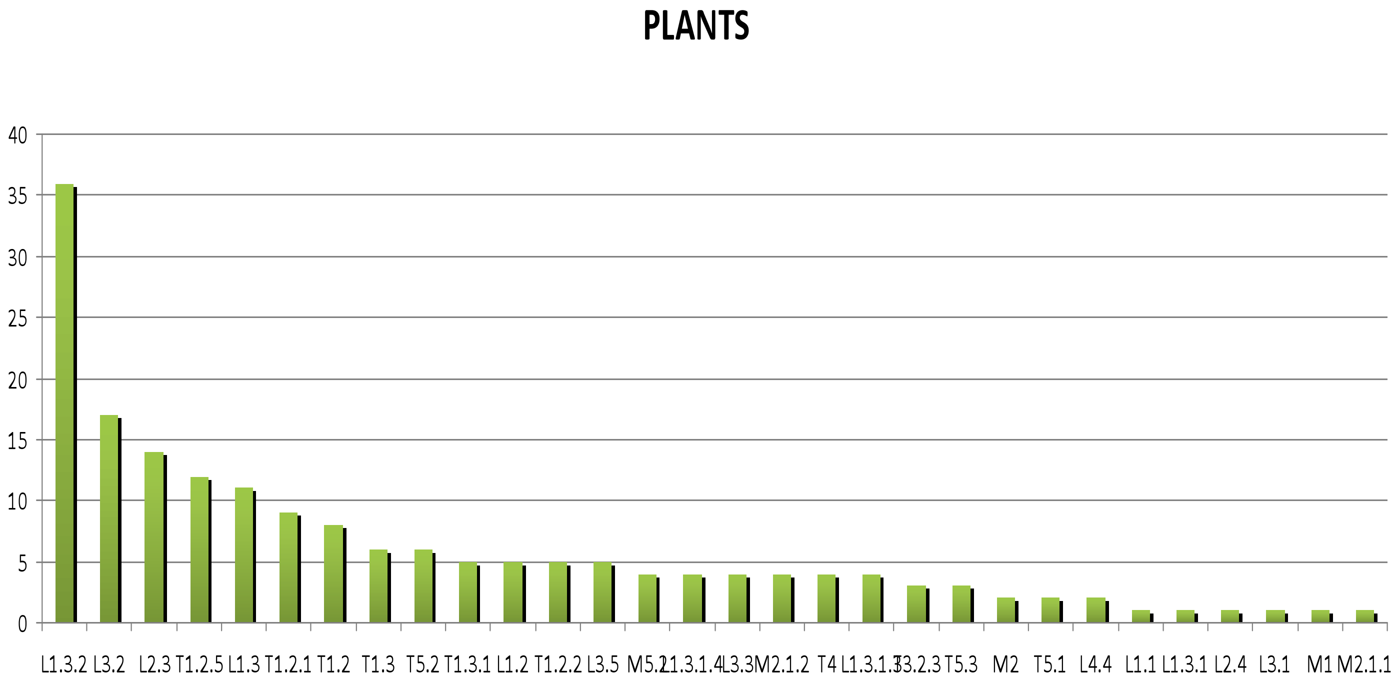
(L) Living Industry

L1 Plant Pathways
L1.1 Importation of Plants for Research
L1.2 Potting Soils, Growing Mediums, Sods and Other Materials
L1.3 Plant Trade (agricultural nursery, landscape, floral, raw logs)
L1.3.1 Plant Parts
L1.3.1.1 Above-Ground Plant Parts
L1.3.1.2 Below Ground Plant Parts
L1.3.1.3 Seeds and the Seed Trade
L1.3.1.4 Aquatic Propagules
L1.3.2 Whole Plants
L2 Food Pathways
L2.1 Live Seafood
L2.2 Other Live Food Animals
L2.3 Plants and Plant Parts as Food
L3 Non-Food Animal Pathways
L3.1 Bait
L3.2 Pet/Aquarium Trade
L3.3 Aquaculture
L3.4 Non-Pet Animals
L3.5 Release of Organisms for Religious, Cultural or Other Reasons
L4 Nonliving Animal and Plant Related Pathways
L4.1 Processed and Partially Processed Meat and Meat Processing Waste
L4.2 Frozen Seafood
L4.3 Minimally Processed Animal Products
L4.4 Minimally Processed Plant Products

(M) Miscellaneous

M1 Biocontrol
M2 Other Aquatic Pathways
M2.1 Interconnected Waterways
M2.1.1 Freshwater Canals
M2.1.2 Marine/Estuarine Canals
M2.1.3 Domestic Waste Streams
M2.2 Interbasin Transfers
M3 Natural Spread of Established Populations
M4 Ecosystem Disturbance
M4.1 Long-Term (highway and utility rights-of-way, clearing, logging)
M4.2 Short Term (habitat restoration, enhancement, prescribed burning)
M5 Garbage
M5.1 Garbage Transport
M5.2 Garbage Landfill

Figure 78. Importance of Pathways by Group of the Critical SIS Species *(cont.)*



PLANTS

Pathways list:

(T) Transportation

T 1 Modes of Transportation
T1.1 Air
T1.2 Water/Aquatic
T1.2.1 Ship Ballast Water
T1.2.2 Hull/Surface Fouling (i.e., Recreational Boats and Vessels)
T1.2.3 Stowaways in Holds
T1.2.4 Superstructures/Structures Above Water Line
T1.2.5 Transportation/Relocation of Dredge Spoil Material
T1.3 Land Terrestrial
T1.3.1 Cars, Buses, Trucks, ATVs. Trailers for recreational boats
T1.3.2 Trains, Subways, Metros, Monorails
T1.3.3 Construction/Firefighting Vehicles
T1.3.4 Hikers, Horses Pets
T2 Military Travel and Transportation of Military Vehicles
T2.1 Baggage/Gear
T2.2 Equipment
T3 Items used in the Shipping Process
T3.1 Containers
T3.2 Packing Materials
T3.2.1 Wood Packing Materials
T3.2.2 Seaweed
T3.2.3 Other Plant Materials
T3.2.4 Sand/Earth
T4 Mail/Internet Overnight shipping
T5 Travel Tourism/Relocation
T5.1 Travelers Themselves
T5.2 Baggage/Gear
T5.3 Pets/Plants and Animals Transported for Entertainment
T5.4 Travel Consumables
T5.5 Service Industries

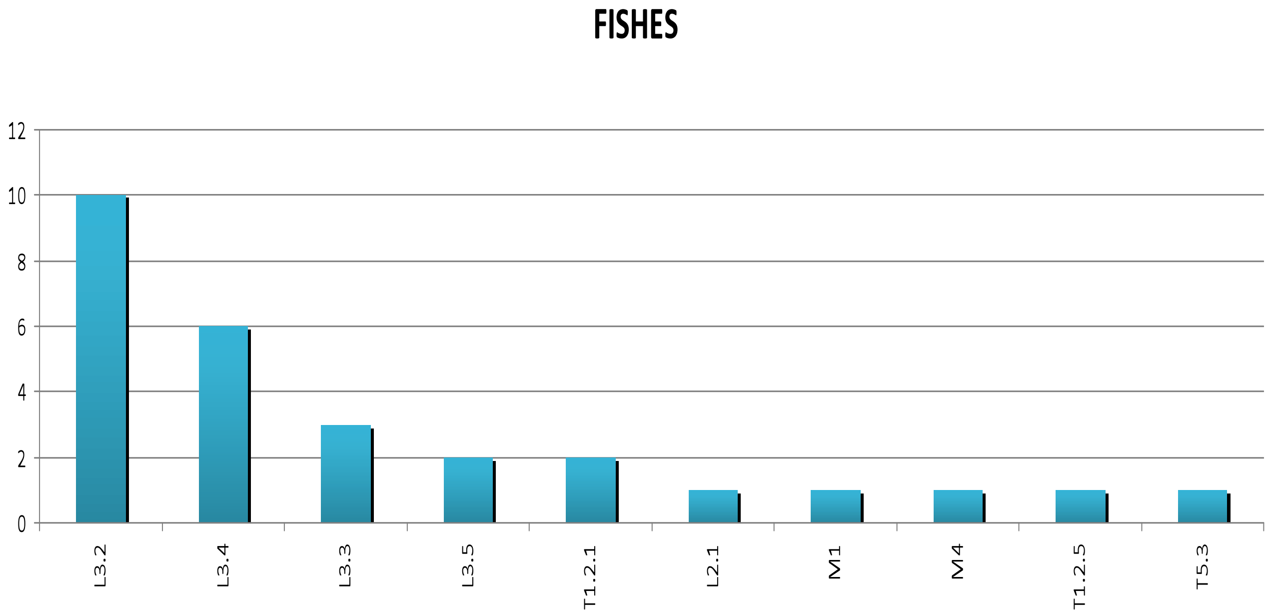
(L) Living Industry

L1 Plant Pathways
L1.1 Importation of Plants for Research
L1.2 Potting Soils, Growing Mediums, Sods and Other Materials
L1.3 Plant Trade (agricultural nursery, landscape, floral, raw logs)
L1.3.1 Plant Parts
L1.3.1.1 Above-Ground Plant Parts
L1.3.1.2 Below Ground Plant Parts
L1.3.1.3 Seeds and the Seed Trade
L1.3.1.4 Aquatic Propagules
L1.3.2 Whole Plants
L2 Food Pathways
L2.1 Live Seafood
L2.2 Other Live Food Animals
L2.3 Plants and Plant Parts as Food
L3 Non-Food Animal Pathways
L3.1 Bait
L3.2 Pet/Aquarium Trade
L3.3 Aquaculture
L3.4 Non-Pet Animals
L3.5 Release of Organisms for Religious, Cultural or Other Reasons
L4 Nonliving Animal and Plant Related Pathways
L4.1 Processed and Partially Processed Meat and Meat Processing Waste
L4.2 Frozen Seafood
L4.3 Minimally Processed Animal Products
L4.4 Minimally Processed Plant Products

(M) Miscellaneous

M1 Biocontrol
M2 Other Aquatic Pathways
M2.1 Interconnected Waterways
M2.1.1 Freshwater Canals
M2.1.2 Marine/Estuarine Canals
M2.1.3 Domestic Waste Streams
M2.2 Interbasin Transfers
M3 Natural Spread of Established Populations
M4 Ecosystem Disturbance
M4.1 Long-Term (highway and utility rights-of-way, clearing, logging)
M4.2 Short Term (habitat restoration, enhancement, prescribed burning)
M5 Garbage
M5.1 Garbage Transport
M5.2 Garbage Landfill

Figure 78. Importance of Pathways by Group of the Critical SIS Species *(cont.)*



Pathways list:

(T) Transportation

T 1 Modes of Transportation
T1.1 Air
T1.2 Water/Aquatic
T1.2.1 Ship Ballast Water
T1.2.2 Hull/Surface Fouling (i.e., Recreational Boats and Vessels)
T1.2.3 Stowaways in Holds
T1.2.4 Superstructures/Structures Above Water Line
T1.2.5 Transportation/Relocation of Dredge Spoil Material
T1.3 Land Terrestrial
T1.3.1 Cars, Buses, Trucks, ATVs. Trailers for recreational boats
T1.3.2 Trains, Subways, Metros, Monorails
T1.3.3 Construction/Firefighting Vehicles
T1.3.4 Hikers, Horses Pets
T2 Military Travel and Transportation of Military Vehicles
T2.1 Baggage/Gear
T2.2 Equipment
T3 Items used in the Shipping Process
T3.1 Containers
T3.2 Packing Materials
T3.2.1 Wood Packing Materials
T3.2.2 Seaweed
T3.2.3 Other Plant Materials
T3.2.4 Sand/Earth
T4 Mail/Internet Overnight shipping
T5 Travel Tourism/Relocation
T5.1 Travelers Themselves
T5.2 Baggage/Gear
T5.3 Pets/Plants and Animals Transported for Entertainment
T5.4 Travel Consumables
T5.5 Service Industries

(L) Living Industry

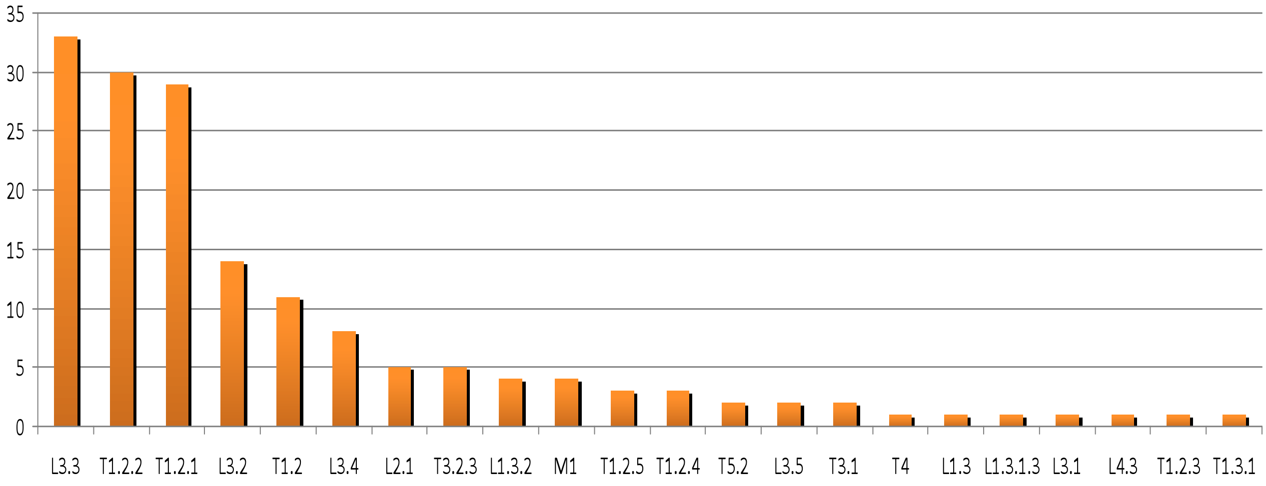
L1 Plant Pathways
L1.1 Importation of Plants for Research
L1.2 Potting Soils, Growing Mediums, Sods and Other Materials
L1.3 Plant Trade (agricultural nursery, landscape, floral, raw logs)
L1.3.1 Plant Parts
L1.3.1.1 Above-Ground Plant Parts
L1.3.1.2 Below Ground Plant Parts
L1.3.1.3 Seeds and the Seed Trade
L1.3.1.4 Aquatic Propagules
L1.3.2 Whole Plants
L2 Food Pathways
L2.1 Live Seafood
L2.2 Other Live Food Animals
L2.3 Plants and Plant Parts as Food
L3 Non-Food Animal Pathways
L3.1 Bait
L3.2 Pet/Aquarium Trade
L3.3 Aquaculture
L3.4 Non-Pet Animals
L3.5 Release of Organisms for Religious, Cultural or Other Reasons
L4 Nonliving Animal and Plant Related Pathways
L4.1 Processed and Partially Processed Meat and Meat Processing Waste
L4.2 Frozen Seafood
L4.3 Minimally Processed Animal Products
L4.4 Minimally Processed Plant Products

(M) Miscellaneous

M1 Biocontrol
M2 Other Aquatic Pathways
M2.1 Interconnected Waterways
M2.1.1 Freshwater Canals
M2.1.2 Marine/Estuarine Canals
M2.1.3 Domestic Waste Streams
M2.2 Interbasin Transfers
M3 Natural Spread of Established Populations
M4 Ecosystem Disturbance
M4.1 Long-Term (highway and utility rights-of-way, clearing, logging)
M4.2 Short Term (habitat restoration, enhancement, prescribed burning)
M5 Garbage
M5.1 Garbage Transport
M5.2 Garbage Landfill

Figure 78. Importance of Pathways by Group of the Critical SIS Species *(cont.)*

INVERTEBRATES



Pathways list:

(T) Transportation

T 1 Modes of Transportation
T1.1 Air
T1.2 Water/Aquatic
T1.2.1 Ship Ballast Water
T1.2.2 Hull/Surface Fouling (i.e., Recreational Boats and Vessels)
T1.2.3 Stowaways in Holds
T1.2.4 Superstructures/Structures Above Water Line
T1.2.5 Transportation/Relocation of Dredge Spoil Material
T1.3 Land Terrestrial
T1.3.1 Cars, Buses, Trucks, ATVs. Trailers for recreational boats
T1.3.2 Trains, Subways, Metros, Monorails
T1.3.3 Construction/Firefighting Vehicles
T1.3.4 Hikers, Horses Pets
T2 Military Travel and Transportation of Military Vehicles
T2.1 Baggage/Gear
T2.2 Equipment
T3 Items used in the Shipping Process
T3.1 Containers
T3.2 Packing Materials
T3.2.1 Wood Packing Materials
T3.2.2 Seaweed
T3.2.3 Other Plant Materials
T3.2.4 Sand/Earth
T4 Mail/Internet Overnight shipping
T5 Travel Tourism/Relocation
T5.1 Travelers Themselves
T5.2 Baggage/Gear
T5.3 Pets/Plants and Animals Transported for Entertainment
T5.4 Travel Consumables
T5.5 Service Industries

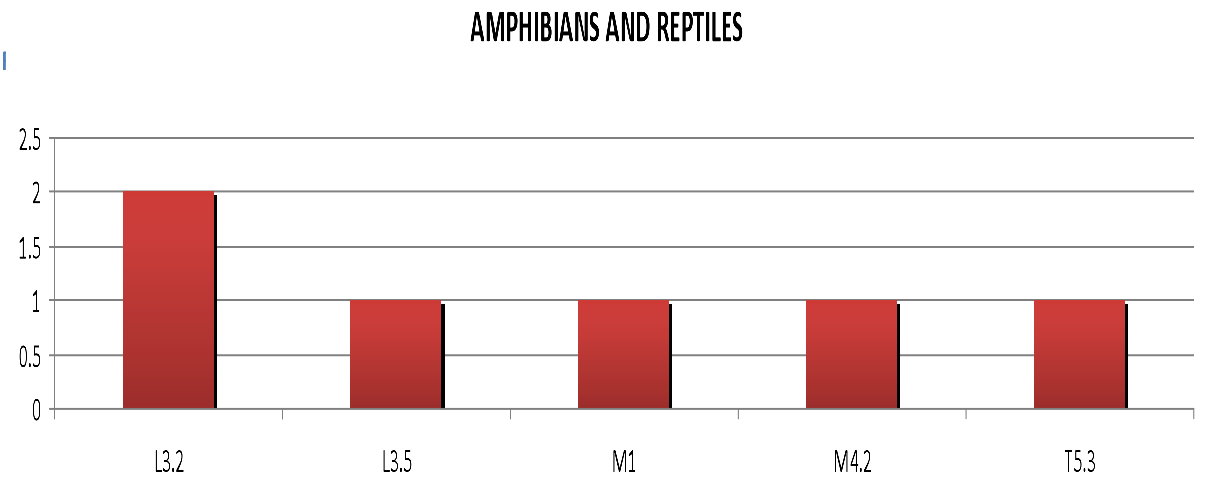
(L) Living Industry

L1 Plant Pathways
L1.1 Importation of Plants for Research
L1.2 Potting Soils, Growing Mediums, Sods and Other Materials
L1.3 Plant Trade (agricultural nursery, landscape, floral, raw logs)
L1.3.1 Plant Parts
L1.3.1.1 Above-Ground Plant Parts
L1.3.1.2 Below Ground Plant Parts
L1.3.1.3 Seeds and the Seed Trade
L1.3.1.4 Aquatic Propagules
L1.3.2 Whole Plants
L2 Food Pathways
L2.1 Live Seafood
L2.2 Other Live Food Animals
L2.3 Plants and Plant Parts as Food
L3 Non-Food Animal Pathways
L3.1 Bait
L3.2 Pet/Aquarium Trade
L3.3 Aquaculture
L3.4 Non-Pet Animals
L3.5 Release of Organisms for Religious, Cultural or Other Reasons
L4 Nonliving Animal and Plant Related Pathways
L4.1 Processed and Partially Processed Meat and Meat Processing Waste
L4.2 Frozen Seafood
L4.3 Minimally Processed Animal Products
L4.4 Minimally Processed Plant Products

(M) Miscellaneous

M1 Biocontrol
M2 Other Aquatic Pathways
M2.1 Interconnected Waterways
M2.1.1 Freshwater Canals
M2.1.2 Marine/Estuarine Canals
M2.1.3 Domestic Waste Streams
M2.2 Interbasin Transfers
M3 Natural Spread of Established Populations
M4 Ecosystem Disturbance
M4.1 Long-Term (highway and utility rights-of-way, clearing, logging)
M4.2 Short Term (habitat restoration, enhancement, prescribed burning)
M5 Garbage
M5.1 Garbage Transport
M5.2 Garbage Landfill

Figure 78. Importance of Pathways by Group of the Critical SIS Species *(cont.)*



Pathways list:

(T) Transportation
T 1 Modes of Transportation
T1.1 Air
T1.2 Water/Aquatic
T1.2.1 Ship Ballast Water
T1.2.2 Hull/Surface Fouling (i.e., Recreational Boats and Vessels)
T1.2.3 Stowaways in Holds
T1.2.4 Superstructures/Structures Above Water Line
T1.2.5 Transportation/Relocation of Dredge Spoil Material
T1.3 Land Terrestrial
T1.3.1 Cars, Buses, Trucks, ATVs. Trailers for recreational boats
T1.3.2 Trains, Subways, Metros, Monorails
T1.3.3 Construction/Firefighting Vehicles
T1.3.4 Hikers, Horses Pets
T2 Military Travel and Transportation of Military Vehicles
T2.1 Baggage/Gear
T2.2 Equipment
T3 Items used in the Shipping Process
T3.1 Containers
T3.2 Packing Materials
T3.2.1 Wood Packing Materials
T3.2.2 Seaweed
T3.2.3 Other Plant Materials
T3.2.4 Sand/Earth
T4 Mail/Internet Overnight shipping
T5 Travel Tourism/Relocation
T5.1 Travelers Themselves
T5.2 Baggage/Gear
T5.3 Pets/Plants and Animals Transported for Entertainment
T5.4 Travel Consumables
T5.5 Service Industries

(L) Living Industry
L1 Plant Pathways
L1.1 Importation of Plants for Research
L1.2 Potting Soils, Growing Mediums, Sods and Other Materials
L1.3 Plant Trade (agricultural nursery, landscape, floral, raw logs)
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L1.3.1.1 Above-Ground Plant Parts
L1.3.1.2 Below Ground Plant Parts
L1.3.1.3 Seeds and the Seed Trade
L1.3.1.4 Aquatic Propagules
L1.3.2 Whole Plants
L2 Food Pathways
L2.1 Live Seafood
L2.2 Other Live Food Animals
L2.3 Plants and Plant Parts as Food
L3 Non-Food Animal Pathways
L3.1 Bait
L3.2 Pet/Aquarium Trade
L3.3 Aquaculture
L3.4 Non-Pet Animals
L3.5 Release of Organisms for Religious, Cultural or Other Reasons
L4 Nonliving Animal and Plant Related Pathways
L4.1 Processed and Partially Processed Meat and Meat Processing Waste
L4.2 Frozen Seafood
L4.3 Minimally Processed Animal Products
L4.4 Minimally Processed Plant Products

(M) Miscellaneous
M1 Biocontrol
M2 Other Aquatic Pathways
M2.1 Interconnected Waterways
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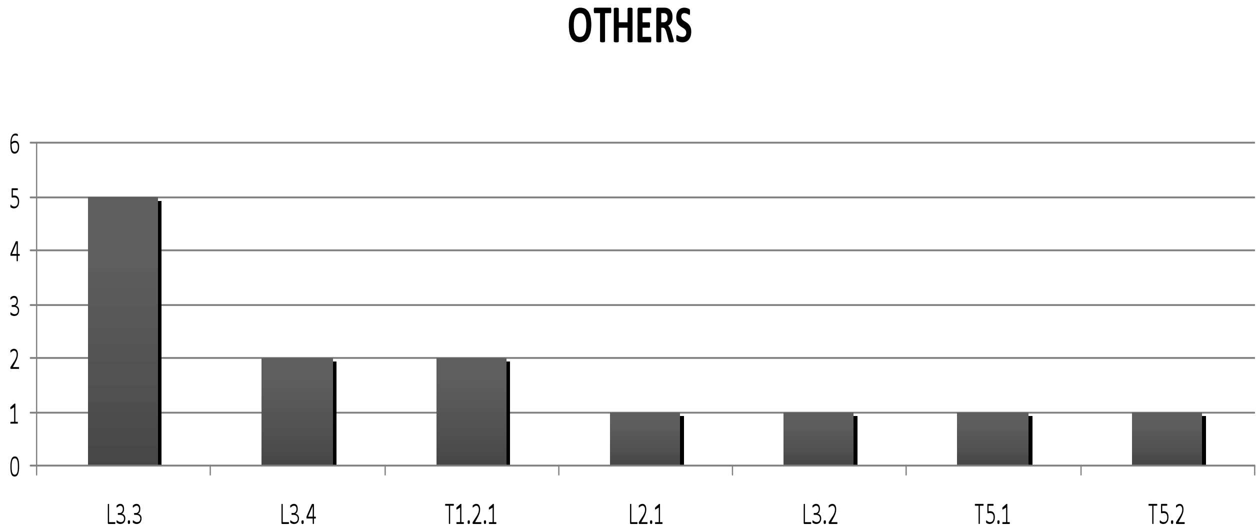
M2.1.2 Marine/Estuarine Canals
M2.1.3 Domestic Waste Streams
M2.2 Interbasin Transfers
M3 Natural Spread of Established Populations
M4 Ecosystem Disturbance
M4.1 Long-Term (highway and utility rights-of-way, clearing, logging)
M4.2 Short Term (habitat restoration, enhancement, prescribed burning)
M5 Garbage
M5.1 Garbage Transport
M5.2 Garbage Landfill

Figure 78. Importance of Pathways by Group of the Critical SIS Species *(cont.)*



Pathways list:

(T) Transportation

T 1 Modes of Transportation
T1.1 Air
T1.2 Water/Aquatic
T1.2.1 Ship Ballast Water
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T1.2.3 Stowaways in Holds
T1.2.4 Superstructures/Structures Above Water Line
T1.2.5 Transportation/Relocation of Dredge Spoil Material
T1.3 Land Terrestrial
T1.3.1 Cars, Buses, Trucks, ATVs. Trailers for recreational boats
T1.3.2 Trains, Subways, Metros, Monorails
T1.3.3 Construction/Firefighting Vehicles
T1.3.4 Hikers, Horses Pets
T2 Military Travel and Transportation of Military Vehicles
T2.1 Baggage/Gear
T2.2 Equipment
T3 Items used in the Shipping Process
T3.1 Containers
T3.2 Packing Materials
T3.2.1 Wood Packing Materials
T3.2.2 Seaweed
T3.2.3 Other Plant Materials
T3.2.4 Sand/Earth
T4 Mail/Internet Overnight shipping
T5 Travel Tourism/Relocation
T5.1 Travelers Themselves
T5.2 Baggage/Gear
T5.3 Pets/Plants and Animals Transported for Entertainment
T5.4 Travel Consumables
T5.5 Service Industries

(L) Living Industry

L1 Plant Pathways
L1.1 Importation of Plants for Research
L1.2 Potting Soils, Growing Mediums, Sods and Other Materials
L1.3 Plant Trade (agricultural nursery, landscape, floral, raw logs)
L1.3.1 Plant Parts
L1.3.1.1 Above-Ground Plant Parts
L1.3.1.2 Below Ground Plant Parts
L1.3.1.3 Seeds and the Seed Trade
L1.3.1.4 Aquatic Propagules
L1.3.2 Whole Plants
L2 Food Pathways
L2.1 Live Seafood
L2.2 Other Live Food Animals
L2.3 Plants and Plant Parts as Food
L3 Non-Food Animal Pathways
L3.1 Bait
L3.2 Pet/Aquarium Trade
L3.3 Aquaculture
L3.4 Non-Pet Animals
L3.5 Release of Organisms for Religious, Cultural or Other Reasons
L4 Nonliving Animal and Plant Related Pathways
L4.1 Processed and Partially Processed Meat and Meat Processing Waste
L4.2 Frozen Seafood
L4.3 Minimally Processed Animal Products
L4.4 Minimally Processed Plant Products

(M) Miscellaneous

M1 Biocontrol
M2 Other Aquatic Pathways
M2.1 Interconnected Waterways
M2.1.1 Freshwater Canals
M2.1.2 Marine/Estuarine Canals
M2.1.3 Domestic Waste Streams
M2.2 Interbasin Transfers
M3 Natural Spread of Established Populations
M4 Ecosystem Disturbance
M4.1 Long-Term (highway and utility rights-of-way, clearing, logging)
M4.2 Short Term (habitat restoration, enhancement, prescribed burning)
M5 Garbage
M5.1 Garbage Transport
M5.2 Garbage Landfill

Discussion

The most important source region for exotic plant introductions into Region 11 is Asia, followed by the American continent as a whole, agreeing with the results published by Benson et al. (2001) for the south eastern United States. In the case of invasive plants, native transplants are not as important a source as in other groups. From this study it can be concluded that the plant trade, particularly from those plants coming from Asia, should be carefully observed and regulated.

In the case of aquatic transportation a great number of plants were associated with dry ballast, probably as seeds and hull fouling. From the aquatic environment source of plants it can be deduced that this is the case of freshwater transportation (fishermen or boats for recreational activities). The problem is more pronounced in the United States, as recreational boating is more widespread there.

As a group, fish are the most numerous exotic species in Region 11 (more than 40% of all taxa). The majority of them are native to the American continent and a great number are native transplants from the Atlantic slope. The major pathway for fish introductions is the intentional stocking of water bodies for sport fishing and the pathways associated with this activity (fish used as bait and aquaculture). The importance of this pathway has been addressed by other authors (Brock et al. 1991) as many dangerous species have been introduced through fish stocking activities (e.g., the Nile perch, *Lates niloticus*). The pathway is so popular that several types of hybrid sport fish have been produced and stocked in fresh waters (e.g., sunshine bass, palmetto bass, muskellunge, crosses between blue tilapia with Nile, Mozambique and Zanzibar tilapia) (Cox 2004).

The aquarium trade also stands as an important pathway for the introduction of exotic fish. Indeed, this industry is a “fashion” industry that relies on variety, which implies the introduction of several different species every day. At the international level, aquarium trade has been widely recognized as an important pathway for the introduction of alien aquatic species into new environments (Taylor et al. 1984; Welcomme 1992). In particular, ornamental fish farms for aquarium trade constitute one of the main pathways for the introduction of exotic species into the natural environment, including hybrid fishes such as convict cichlid X firemouth, green terror X blue acara, molly X guppy, etc. (see Cox 2004). This is in part due to the high number of continuously changing species and varieties of fish produced and the closeness to natural freshwater bodies (Copp et al. 2005). Most of the species come from freshwater environments and Texas is the state with the greatest presence of exotics (Fuller et al. 1999).

The group of amphibians and reptiles is represented by few species, all of them native to the Americas, with a great majority from North America, chiefly from the Atlantic slope. This is understandable, due to the great richness of amphibian and reptile biodiversity on this continent. The pet-aquarium trade is the most important pathway and shows that pet shops should be the target of careful inspections. The plant trade is also an important pathway for this group, presumably due to the natural association of amphibians and reptiles with plants (food source, shelter, habitat, etc.).

The great majorities of amphibian and reptile species come from freshwater environments and are evenly distributed throughout Region 11.

The Americas are also the main source region for exotic invertebrate species introductions into Region 11. This group differs from the others because it is the only group in which species of marine and brackish origin are more important than those of freshwater origin. Aquatic transportation (ballast water and hull fouling) is the most important pathway and has produced introductions from all continents; thus control and preventive measures should be applied to all international shipping arriving in Region 11. Aquaculture and the aquarium trade are also important pathways, as a consequence of contamination (aquaculture) or intentional introductions (aquarium trade). In the case of aquaculture, Hazard Analysis and Critical Control Point (HACCP) methods for preventing the unintentional introduction of invasive species should be implemented (Pitman 2003), while for the pet-aquarium trade, risk analysis for invasive species should be mandatory (Mendoza et al. 2009).

Biological contamination of commercial aquaculture species is also the main pathway for the introduction of bacteria and viruses, particularly from countries of the Asian continent. In this case, besides HACCP methods, a thorough sanitary inspection under international rules (e.g., those of the World Organisation for Animal Health, OIE) should be performed as well.

Of the six invasive freshwater mammal species registered as being in the United States (*Castor canadensis, Hydrochaeris hydrochaeris, Myocastor coypus, Ondatra zibethicus, Otaria flavescens, Zalophus californicus*), only one, the nutria, was found to be by far the most established and invasive species in Region 11 (NAS 2010). Economic losses as a result of its impact on infrastructure and agricultural crops (sugarcane and rice mostly) probably exceed $1 million annually. Businessmen who thought that its fur pelts would be in great demand brought the nutria to the United States. However, this demand was never realized and their prospective ranchers freed the nutria into the wild. Once there, their very high reproduction rates allowed them to eventually overrun the southern gulf marshes in the states of Louisiana and Texas, consuming much of the available vegetation and causing great damage. The nutria then moved inland to feed on the sugar and rice fields in the two states (Trade Environment Database 2010).

Conclusion

Overall, 94 of the 373 invasive species in the Region are considered to be of critical concern. Even if these do not constitute a majority, they are still a very significant number. While most of the exotic species are native transplants from the Atlantic slope and have been introduced by sport fishing, aquaculture, the aquarium trade, use as bait, and via aquatic transportation, the majority of the critical species come from other continents. Nor are they uniformly distributed throughout the continent. Out of the 94, 6 are currently found only in Mexico, 65 occur only in the US, and only 2 are potential invasive species reported in states neighboring the region. Hence, the current threat to the Laguna Madre comes from the larger number of invasive species already established in the portion of the region in the United states or present in the neighboring vicinity.

Some pathways of introduction, such as fish stocking, bait release, and those pertaining to boating are related (e.g., fish are cultured to be later stocked in freshwater bodies out of their native region as game fish, or are fed with bait fish from other regions, fishing requires boats that are introduced to different water bodies and are possibly contaminated by hitchhiking organisms). Finally, aquatic transportation and the aquarium trade are significant pathways for plants, fish and invertebrates.

In order to protect the native ecosystem of Region 11 it will be necessary to implement not only preventive actions, such as HACCP and risk analysis, but also coordinated binational actions of control and eradication of those species determined as critical in this study.

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