Galveston Bay Invasive Species Risk Assessment Final Report

PREPARED IN COOPERATION WITH THE
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY AND
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Title Page Photos:

Chinese tallow (*Triadica sebifera*) and elephant ear (*Colocasia esculenta*) invading the shoreline of Armand Bayou in Houston, Texas 2003; Photo courtesy Dr. Brenda Weiser, EIH/UHCL

Brazilian Peppertree (*Schinus terebinthifolius*), Hight, Stephen D., Image 0002012, www.invasive.org

Channeled apple snail (Pomacea canaliculata) found along the shoreline of Armand Bayou in Houston, Texas 2003; Photo courtesy Dr. Brenda Weiser, EIH/UHCL

Chinese tallow (*Triadica sebifera*), Miller, James H., Image 0016234, www.invasive.org

Red imported fire ant (*Solenopsis invicta*), Bauer, Scott, Image 1321080, www.invasive.org

Giant Salvinia (S*alvinia molesta),* Biological Control USDA APHIS - Oxford, North Carolina Archives, Image 1148172, www.invasive.org

Grass Carp (*Ctenopharyngodon idella*), Biological Control USDA APHIS - Oxford, North Carolina Archives, Image 1149123, www.invasive.org

Chinese mitten crab (*Eriocheir sinensis*), California Dept of Fish & Game, accessed via www.gsmfc.org

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1. Introduction

1.1. Defining the Invasive Species Problem

Biodiversity at the global and regional scales is organized into evolutionary lineages that are spatially distributed throughout the biosphere. The spatial distribution of these species is the basis of a field of knowledge known as biogeography. Much of biogeography can be understood by describing the arrangements of assemblages of species into ecosystems and ecoregions. Species that occur together and interact evolve adaptations that facilitate their coexistence.

Throughout geologic time, natural barriers (e.g. oceans, elevation, and climate) separated one ecoregion from another. Species typically remained within their biogeographic range, except for rare range expansions. Mankind has increasingly violated the natural biogeographic boundaries through human-assisted species introductions as a function of migration, settlement, cultivation, and trade. As a result, humans have dramatically altered biogeography by accidentally and intentionally dispersing species into ecoregions and ecosystems where they had not previously resided. Species occurring outside their natural biogeographic range are identified under a collection of terms including: nonindigenous, exotic, and non-native species. The term, invasive species, is also used interchangeably with them, but in actuality represents a different, more harmful type of exotic species.

When introduced into new ecosystems, non-native species are often unable to survive or reproduce because conditions are so dissimilar to their native habitats. But occasionally, when the conditions are right, exotic species become established. Invasive species are those exotics that have the capacity to establish and increase their population size and range in a new biogeographic region. The invaders accomplish this by preying on native species or by out-competing native species for ecological space. As a result, the biodiversity of native flora and fauna in a region can be negatively impacted.

Nonindigenous species have perhaps been introduced to new ecosystems for centuries by human activities, e.g. pastoralists moved sheep and goats to new regions, agriculturists moved cultivated plants and animals to new regions, and more recently, intercontinental travel by airplanes and ships has moved invaders to new locations. Natural events (e.g. storm events and changes in ocean currents) have also played a role in the introduction of invasive species (Carlton, 1989). Some species, particularly marine or estuarine species, were probably introduced by human activity prior to the use of biological surveys and are considered to be cryptogenic, or of unknown origin. Cryptogenic species may be thought to be native to an area, but in actuality may be an invasive introduced long ago.

Some non-native species are beneficial; providing benefits to humans or occupying an important ecological niche (e.g. the European honeybee). Other invaders have detrimental, yet subtle effects, such as the change in species composition of a prairie when vaseygrass is introduced. However, some invaders represent a major threat to the biodiversity of an ecoregion, such as the brown tree snake that has decimated the bird fauna of Guam or the monotypic Chinese tallow forest that creates an entirely new ecosystem replacing native wetlands or coastal prairie as is occurring in the Galveston Bay area.

While invasive species pose a great risk to terrestrial ecosystems, estuaries are frequent locations of exotic species invasions as well. A single estuary may contain tens to hundreds of invasive species from a variety of major taxonomic and trophic groups (Ruiz et al., 1997). Each non-native species will interact with and impact the new environment in a unique and often unforeseen manner. This project was designed to evaluate, through the technique of comparative risk assessment, the risk posed by invading and potentially invasive aquatic and terrestrial species to ecosystems in the Lower Galveston Bay Watershed.

1.1.1. Impacts of Invasive Species on Human Uses

The presence of invasive species has a negative impact on human uses of natural resources, causing economic and social repercussions; many of which are not yet recognized. Economic costs include monetary resources and human effort spent to control and eradicate invasives as well costs associated with the loss or inefficient use of resources. Societal costs include decreased quality of life and threats to human health.

Examples of invasive species causing the loss or inefficient use of resources abound. Estuarine invasives, such as the Bryozoan sauerkraut grass, foul commercial shrimping gear in Galveston Bay and cause an economic loss to shrimpers through increased effort and reduced harvest. Municipal and industrial water uses are made less efficient by invasives such as the zebra mussel which encrusts intake pipes in the Great Lakes. The channeled applesnail decimated rice production in many parts of Southeast Asia and could decrease rice harvests along the Gulf Coast.

Recreational and aesthetic uses of natural resources and overall quality of life are negatively affected by invasive species. Aquatic weeds choke numerous waterbodies, in Texas making recreational boating in some areas nearly impossible. Red imported fire ants cause various ecological losses, such as colonial nesting bird mortality, and can also make a poorly located outdoor activity a very unpleasant experience.

Invasive species can also effect human health. Invasive pathogens include the Asian tiger mosquito, West Nile virus, and exotic strains of *Vibrio parahaemolyticus*. Invasive-related human illnesses occur across the country and are seen every summer with the presence of the Asian tiger mosquito and West Nile virus. In the summer of 1998 hundreds of people nationwide became ill after ingesting Galveston Bay oysters contaminated with an exotic strain of *Vibrio parahaemolyticus* never before found in the U.S.

1.1.2. Vectors of Introduction

Invasive species are introduced to new biogeographic areas through a number of introduction pathways, or vectors of introduction. Introductions can be accidental or intentional and are often associated with commercial activity. Pathways for introductions of terrestrial invasive species include: accidental introductions via plant nurseries and horticulture; planned introductions of biocontrol agents by the agriculture industry; accidental introductions via overland trade routes; and accidental releases from research and scientific institutions.

Aquatic invasives are accidentally or intentionally introduced through a number of pathways including: ship ballast water, ship hull fouling, vessel cargo, aquaculture, the aquarium trade, horticulture/water gardens, live seafood markets, biological control methods, movement through manmade channels, release of live bait, and release from scientific and research institutions.

While all of the vectors listed above play active roles in the introduction of invasive species in the Lower Galveston Bay Watershed, the comparative risk posed by each is not known. For instance, which pathway has a greater impact on the ecology and human resource uses in the watershed: ballast water, plant nurseries, or the aquarium trade? It is important that this question be answered so that resources can be sufficiently targeted to the most active introduction pathways. Targeting the correct introduction pathways will go a long way toward prevention and early detection of invasive species in the watershed.

1.2. The Need for Invasive Species Management on a National Scale

Coblentz (1990) placed human-induced impacts affecting resource conservation into three categories: pollution, inappropriate resource use, and exotic organisms. He stated that while pollution and inappropriate resource use are serious issues, they are often correctable. On the other hand, exotic organisms may perhaps represent the greatest crisis due to their unpredictability, pervasiveness, and sometimes-irreparable impacts.

Estuarine systems and associated watersheds are increasingly connected on a global scale. Trade routes connect the continents and vessels are able to make transoceanic journeys in days versus weeks and months. Regional connectivity of aquatic systems has also increased through time via networks of man-made canals constructed for the inland and coastal transport of goods, people, and water (Mills et al., 1999).

Some introduced species exist in human-dominated habitats, while others are capable of spreading into natural ecosystems and displacing native species. Both can yield negative results. For example, Norway rats are unlikely to spread to natural ecosystems in North America, but they can reach high abundance in human-dominated habitats and serve as important reservoirs of pathogens. For reasons of public health, exotic rats are usually subject to control programs.

The Galveston Bay Invasive Species Risk Assessment Project is focused on species invasions of the Lower Galveston Bay Watershed. The following case studies are offered as examples of invasive species impacts documented in similar ecosystems in North America.

1.2.1. Case Study: Great Lakes

Several of the most studied cases regarding impacts from invasive species have occurred in the Great Lakes. The first drastic impact occurred in the early 1920’s with the sea lamprey moving through the Welland Canal into Lake Erie and eventually into the rest of the Upper Great Lakes (University of Wisconsin Sea Grant Institute, 1998). The sea lamprey parasitized lake trout, once one of the most valuable commercial fish species of the Great Lakes, and decimated their population. In combination with over fishing, the sea lamprey invasion led to the extinction of three endemic fishes (Simberloff, 2000). In addition to the loss of a commercial fishery, the decline of lake trout led to a cascading effect that altered species composition at lower tropic levels.

The zebra mussel (*Dreissena polymorpha*) invaded the Great Lakes more recently, in the 1980s, and has escaped from the Great Lakes to invade 20 states and two Canadian provinces along the Mississippi, Illinois, Ohio, Mohawk, Hudson, St. Lawrence, Cumberland, Tennessee, and Arkansas Rivers and tributaries (University of Wisconsin Sea Grant Institute, 2001). Zebra mussels are very prolific and settle in great densities inside water pipes and on other hard surfaces. They can completely clog cooling pipes and cause damage to industrial and power plants.

Costs of control efforts for the zebra mussel alone are estimated to exceed $13 billion per year in the U.S. Zebra mussel concentrations are often sufficient to reduce dramatically phytoplankton densities in lakes and rivers, causing a cascading effect on the mussel's competitors and on higher trophic levels. Many species of rare freshwater mussel are threatened with extinction due to the changes associated with invasion of their habitat by the zebra mussel (Simberloff, 2000).

1.2.2. Case Study: San Francisco Bay

San Francisco Bay is regarded as the most invaded aquatic ecosystem in North America (Cohen and Carlton, 1995) and as a result is another well-studied estuarine system for impacts of invasive exotic species. The following quotations give some insight into how serious the problem is for San Francisco Bay and the potential risk to Galveston Bay.

> "Nonindigenous aquatic animals and plants have had a profound impact on the ecology of this region. No shallow water habitat now remains uninvaded by exotic species and, in some regions, it is difficult to find any native species in abundance. In some regions of the Bay, 100% of the common species are introduced, creating 'introduced communities'."
>
> (Cohen and Carlton, 1995)

> "The Chinese [or Asian] clam (*Potamocorbula amurensis*), is an example of an invasive species that has had a large effect on the ecology of San Francisco Bay. First collected in San Francisco Bay in 1986, *P. amurensis* is thought to have been introduced via the ballast water of Asian cargo vessels. The Asian clam is tolerant of a wide range of salinities, water temperatures, depths, and substrate types. Within two years of the first reports of the Asian clam in San Francisco Bay, the species had spread throughout the estuary."
>
> (Carlton et al., 1990).

> "It quickly reached densities of greater than 10,000 individuals per square meter. Within one year the composition of the soft substrate community had changed dramatically, with *P. amurensis* comprising more than 95 percent of its biomass.
>
> This single species forms a carpet over the floor of San Francisco Bay and estuary, displacing the former benthic community and causing sediment disturbance.
>
> The Chinese clam is a suspension feeder and has been found to consume large quantities of phytoplankton. This has resulted in a change in the phytoplankton

dynamics in San Francisco Bay and has been blamed for the collapse of some fisheries in the area."

(Carlton et al., 1990)

1.2.3. Case Study: South Florida

Southern Florida is the most tropical ecoregion in the contiguous U.S. and is a very accommodating region for invasive species from subtropical and tropical countries. Fish that are released from tropical fish farms or aquaria have become established in such densities that they comprise over 75% of the fish fauna in many canals and rivers of South Florida. More than 150 species of nonindigenous fish have been introduced to the State's waters (USGS, 2001).

The Everglades is seriously threatened by invasive plants (e.g. *Melaleuca*, Salt cedar, and Brazilian pepper) that evapotranspirate water at rates that reduce water tables and threaten native grasses. Approximately 1.7 million acres of Florida's remaining natural habitat have been invaded by invasive species (Florida DEP, 2003).

> "The Australian paperbark tree [*Melaleuca quinquenervia*] has replaced native plants, such as sawgrass, over 400,000 acres of south Florida, because it has a combination of traits (for example, spongy outer bark and flammable leaves and litter) that increase fire frequency and intensity. Many birds and mammals adapted to the native plant community declined in abundance as paperbark spread."
>
> (Simberloff, 2000)

> "Brazilian pepper now covers hundreds of thousands of acres in south and central Florida, as well as many of the islands on the east and west coasts of the state. Biannual exotics surveys conducted by the South Florida Water Management District indicate that Brazilian pepper is the most widespread exotic plant in the state - occupying more than 700,000 acres."
>
> (Ferriter, 1997)

1.3. The Need for Invasive Species Management on a Regional Scale

1.3.1 Gulf of Mexico

The U.S. coast of the Gulf of Mexico contains a network of estuarine systems stretching from the Florida Keys westward to the Laguna Madre of Texas. Each estuary has its own unique set of hydrological and climatological conditions, habitats, and living resources. However, similarities (e.g. salinity and temperature regimes) and connectivity (e.g. trade routes, Gulf currents, offshore oil exploration platforms) between the estuaries periodically enable invasive species to use the estuaries as "stepping stones" along their invasion route from one side of the Gulf to the other. Giant Salvinia (*Salvinia molesta*) is an example of an invasive species first reported in Florida in 1930 that eventually spread along the Gulf Coast with the first reported sighting in southeast Texas in 1992.

Several species of invasive invertebrates affecting Gulf of Mexico estuaries east of Galveston Bay have the potential to invade Galveston Bay. In the summer of 2000, large densities of the Australian spotted jellyfish (*Phyllorhiza punctata*) were reported in Mobile Bay, the Mississippi

Sound and in Lake Bourne, Louisiana. The invader did not colonize Texas, although the species has been reported in state waters. The invasions in Alabama, Mississippi, and Louisiana have been less severe in subsequent years. However, invasion theory suggests that the chances of a successful invasion increase with repetitive introductions of a species. Scientists are examining the factors that may have lead to the jellyfish population explosion in 2000 (e.g. Gulf currents, ballast transport, offshore oil platforms, and anoxia), but no concrete explanation exists. Invasion ecologists have a term for near misses such as this; “ecological roulette” (Carlton and Geller, 1993). In the year 2000 Texas estuaries dodged the bullet, but experts do not know what will happen if the spotted jellyfish or another invasive such as the zebra mussel becomes established in Texas coastal waters.

The U.S. EPA’s Gulf of Mexico Program (GMP), the Gulf States Marine Fisheries Commission (GSMFC), and the U.S. Geological Survey (USGS) are three examples of agencies working to increase invasive species communication and collaboration between the Gulf States. In 2000, the GMP released its survey of invasive species issues of the Gulf of Mexico region (EPA, 2000), which inventoried invasive species and detailed invasive species management issues for Gulf Coast states. The GMP also provides funding on an annual basis for the prevention and control of invasive species along the Gulf of Mexico coast.

The GSMFC, in partnership with the USGS and the Smithsonian Environmental Research Center (SERC), sponsors web-based information resources on non-native aquatic species of the Gulf of Mexico. Visitors to the website can access multiple databases providing information on nonindigenous species of the Gulf of Mexico Region.

The USGS also sponsors the Nonindigenous Aquatic Species (NAS) information resource. Users can access species fact sheets and geographically referenced information including species distribution maps. The National Wetlands Research Center (NWRC) of the USGS conducts research on invasive species impacts, including impacts of Chinese tallow, nutria, and aquatic plants on coastal habitats.

1.3.2. Texas

Texas, like every other state in the country, has its share of nonindigenous species. After centuries of accidental and intentional introductions, the costs of biological invasions to the environment and society are just now being realized. The Office of Technology Assessment (OTA, 1993) estimated that invasive species costs for the United States averaged $1.1 billion per year. More recently, Pimentel et al (1999) estimated that invasive species cost the United States $138 billion per year in impacts and control costs. While there is no estimate for the cost of all invasive species impacts in the State of Texas, Pimentel (1999) provides some estimates for single species:

- $300 million per year in damages to Texas livestock, wildlife, and public health caused by fire ants; another $200 million per year for fire ant control costs in Texas
- Feral dogs cost Texas $5 million per year in livestock losses

In order to quantify the impacts to biodiversity and human uses in Texas one must first be able to accurately describe the problem. Although we have estimates of how many species have been introduced to the State, the exact number is not known. No statewide tally of aquatic and terrestrial species has ever been conducted. An idea of the scope of the invasive species problem in Texas can be gleaned from a number of resources.

The Digital Flora of Texas Project identifies 497 vascular plant species as being introduced to the State of Texas, although only a small percentage will most likely become invasive (Williamson and Fitter, 1996). As seen in Table 1.3.1, it is estimated that 145 aquatic species have been introduced into the State's waterways. In 1992, a Texas Parks and Wildlife Department (TPWD, 1992) statewide survey of landowners reported 67 species of exotic mammals inhabiting the rangelands of the State as reported in a survey of private landowners.

Table 1.3.1. According to Benson (2000), 145 nonindigenous, aquatic species have been introduced into Texas waters.

	Number of species
Amphibian	4
Crustacean	2
Fish	107
Mammal	1
Mollusc	7
Plant	21
Reptile	3
Total Number of Species	**145**

The TPWD and the Texas Department of Agriculture (TDA) are the leading state agencies dealing with invasive species issues in Texas. The TPWD maintains a list of exotic finfish (33 taxa), shellfish (7 taxa) and aquatic plants (11 taxa) that cannot be imported, possessed, sold, or placed into waters of the State of Texas unless an exception or permit has been granted by the agency. The TPWD also conducts invasive species research, monitoring, eradication, and education activities through its Inland Fisheries and Coastal Fisheries Divisions.

Invasive species efforts of the TDA focus primarily on exotic plants. The TDA spearheads the Texas Riparian Invasive Plant Task Force (TXRIP) that provides a regular forum for the discussion of invasive plant issues and efforts in the State. In 2003 the TDA developed a Noxious Plant List containing 27 species of aquatic and terrestrial plants that are prohibited (via sale, distribution, or importation in live form) in the State of Texas. The proposed rule underwent public comment in 2003 and can be viewed under Title 4 of the Texas Administrative Code (4 TAC §19.200).

Many universities and university-affiliated research organizations in the region, including Rice University, Texas A&M University, the University of Houston, the University of Texas, Texas Sea Grant, and others conduct and fund research on invasive species impacts and control techniques.

1.4. Current Efforts on Invasive Species in the Lower Galveston Bay Watershed

1.4.1. Objectives of *The Galveston Bay Plan*

The stakeholder-led Galveston Bay Estuary Program (GBEP), formerly the Galveston Bay National Estuary Program, is a program of the Texas Commission on Environmental Quality

(TCEQ). The GBEP was established in 1989 to develop a Comprehensive Conservation Management Plan (CCMP) for the Galveston Bay system. The CCMP for the Galveston Bay area is called *The Galveston Bay Plan* (*The Plan*), a consensus-based program to manage Bay resources with fewer negative impacts and to restore components of the Bay system impacted by poor management decisions made in the past.

The Plan has many goals that relate to the well-being of the Bay, including two actions aimed at reducing the threat from exotic, invasive species. The objective of these actions is to reduce the abundance of selected exotic (invasive) species by ten percent by 2005. During the 5-year *Plan* review process, invasive species action items in *The Plan* were elevated to a high priority status (GBEP, 2001).

Action SP-9 is entitled, *Improve Enforcement of Prohibitions Against the Introduction of Exotic Species*. The steps in the action involve identifying and enhancing agency regulations against introduction of exotic species, disseminating information about these regulations, and hiring and training enforcement officers to ensure implementation of the regulations. The U.S. Fish and Wildlife Service (USFWS) has primary responsibility along with the TPWD and the U.S. Coast Guard (USCG) in cooperation with the National Marine Fisheries Service (NMFS) and the U.S. Environmental Protection Agency (EPA).

Action SP-10 is entitled, *Identify and Implement Techniques for the Control of Problem Exotic Species*. The steps in the action call for the TPWD to identify effective techniques, pilot-test for control effectiveness, and expand successful programs. Other cooperating agencies are NMFS, USFWS and the USDA Natural Resources Conservation Service (NRCS).

Since the publication of *The Plan*, there has been a coordinated effort to control some exotic, invasive species (e.g. Chinese tallow, water hyacinth, and giant Salvinia). It appears that more has been expended in this effort than that which *The Plan* required. However, effective techniques for the elimination of exotics from terrestrial and aquatic habitats are still very limited and costly, making the additional efforts warranted.

Since implementation of *The Plan* began in 1995, federal regulations dealing with ballast water and aquatic nuisance species control have been developed. The National Invasive Species Act of 1996 (NISA) amended the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. The NISA gave the U.S. Coast Guard the authority to establish rules regarding ballast water exchange in waters of the United States. In 1998, the Coast Guard published a provisional rule that encouraged all ships arriving at U.S. ports from outside of the 200 mile Exclusive Economic Zone (EEZ) to exchange ballast water at sea, and required implementation of a national ballast water exchange information and reporting program. In a June 2002 report to congress, the Secretary of Transportation reported that the level of ballast water exchange reporting was inadequate, given that no penalties could be levied for noncompliance with the Coast Guard reporting requirements.

In 2003, the U.S. Coast Guard and its parent agency, the Department of Homeland Security, proposed a new rule requiring ballast water exchange reporting for all vessels operating in U.S. waters regardless of vessel origins inside or outside of the EEZ. The proposed rule also required a mandatory ballast water management program for all vessels equipped with ballast tanks coming to U.S. ports from beyond the EEZ. As part of this program, a ship coming from outside of the EEZ would be required to do one of the following: 1) exchange ballast water at least 200 nautical miles offshore; 2) retain ballast water onboard the vessel while in U.S. ports; 3) use a Coast Guard-approved method of alternative ballast water management; or 4) discharge ballast water to an approved reception facility. The public comment period for the new proposed rule ended in October 2003. The final rule is pending (EPA, 2003).

A recent development in international regulations dealing with ballast water occurred in February 2004. Member states to the International Maritime Organization (IMO), a United Nations agency, successfully adopted the *International Convention for the Control and Management of Ships Ballast Water & Sediments*. The new Convention seeks to prevent, reduce, or eliminate the transfer of harmful aquatic organisms and pathogens through ships' ballast water and sediments (IMO, 2004). Specific measures include the implementation of ballast water management plans and maintenance of ballast water management record books by individual ships, the development of set standards for ballast water management procedures with no grandfathering of older vessels allowed, and incentives to test and evaluate emerging ballast water treatment technologies. The Convention will enter into force twelve months after ratification by 30 of the 74 participating member states (IMO, 2004).

1.4.2. Current Invasive Species Efforts in the Lower Galveston Bay Watershed

Historically, invasive species impacting other regions, such as the Great Lakes, Chesapeake and San Francisco Bays, have received more attention in terms of funding aimed at research, monitoring, control, prevention, and education. However, invasive species efforts in the Lower Galveston Bay Watershed and along the Gulf Coast are increasingly the focus of control, monitoring and research efforts. The GBEP works with a number of local, state and federal agencies and organizations on projects aimed at invasive species control, monitoring, and habitat restoration. Ongoing projects include those listed in Table 1.4.1.

Table 1.4.1. Current invasive species projects in the Lower Galveston Bay Watershed.

Project Title	**Description**	**Partners**
Invasive Species Control in Armand Bayou Nature Center	Removal of Chinese tallow and woody invasive species from coastal prairie and wetlands on Taylor Bayou at Armand Bayou Nature Center (ABNC)	GBEP, ABNC, and Gulf of Mexico Program
Tidal Bayous Survey	Faunal survey of three Galveston Bay tributary streams to determine extent and distribution of exotic aquatic species	GBEP and TPWD
Galveston Island Wetland and Habitat Enhancement	Control of Brazilian pepper tree and other invasive species on Galveston Island	GBEP, TPWD, and Galveston Bay Foundation
Invasive Species Control and Public Outreach in the Bay Area	Education and outreach campaign with local governments for control of invasive species	GBEP and Houston-Galveston Area Council
Invasive Species Control at Virginia Point	Control of Chinese tallow and other invasive species at Virginia Point Preserve	US Fish and Wildlife Service (USFWS) and Scenic Galveston, Inc.

Several projects in the development stages in the Lower Galveston Bay Watershed are listed in Table 1.4.2.

Table 1.4.2. Developing invasive species projects in the Lower Galveston Bay Watershed.

Project Title	Description	Partners
Deep-rooted Sedge Control and Research	Study of control methods for deep-rooted sedge on Texas City Prairie Preserve	USFWS, the Nature Conservancy (TNC), and GBEP
Invasive Species Control and Habitat Restoration at Clear Creek Nature Park	Control of Chinese tallow and other invasive species at Clear Creek Nature Park	GBEP and City of League City
Channeled Apple Snail Research	Study of feeding habits, distribution, and control methods for channeled apple snail in Galveston Bay Watershed	GBEP, TPWD, and ABNC

2. Project Scope and Methods

2.1. The Lower Galveston Bay Watershed

The Galveston Bay Estuary and surrounding watershed are located in Southeast Texas near the heavily populated Houston-Galveston metropolitan area. The 2000 United States Census reported a population in the area of nearly 4.5 million people (Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, and San Jacinto counties).

Situated on the Western Gulf Coastal Plain, the region is home to a myriad of activities that rely upon and impact the Galveston Bay environment and associated watershed. Activities include, but are not limited to, commercial and recreational fishing, shipping and transportation, industrial and urban development, and agriculture. These activities and others combined with a growing population place various stresses upon the bay environment and offer avenues for introduction of potentially invasive species.

Invasive species can be accidentally or intentionally introduced by human activities into ecosystems in which the species are not natural components. The Galveston Bay system is no exception. Some invasive species have become naturalized in and around the estuary and are reproducing without human support. Once established, these non-native species out-compete or prey upon native species leading to the destruction of important habitats, the reduction of biodiversity, and a resultant loss of ecological balance within the system.

Although no estimate is available for Texas or the Galveston Bay region, more than $130 billion are lost annually in the United States to damage caused by invasive species (Pimentel, et al. 1999). The amount is considered to be a conservative estimate given that it does not include losses to ecosystem services, biodiversity or aesthetic values.

This project is funded by the Galveston Bay Estuary Program (GBEP), a program of the Texas Commission on Environmental Quality (TCEQ). As mentioned in Section 1.4.1, the GBEP is responsible for implementation of the *Galveston Bay Plan* (*The Plan*); the Comprehensive

Conservation and Management Plan for the Galveston Bay Estuary and associated watershed. During the five-year Plan review process, invasive species were identified as the second highest threat to species population protection in the Galveston Bay Estuary (declining trends of certain marine species and birds were identified as the highest threat to species population protection) (GBEP, 2001).

The Galveston Bay Invasive Species Risk Assessment Project accumulated and assessed existing information on the identity, characteristics, and impacts of exotic species invading natural ecosystems in the lower Galveston Bay watershed. A risk assessment was conducted to identify invasive species posing the greatest ecological risk. Future threats posed by species currently invading similar ecosystems along the Eastern Gulf of Mexico Coast were also identified.

2.2. Compiling the Species list

As seen in Appendix A, 296 aquatic and terrestrial invasive species were identified as current or future threats to the Lower Galveston Bay Watershed. The list was compiled through a review of existing information and was used as the starting point for the risk assessment process (Section 2.3). Techniques used to compile the species list included: a literature review, an internet/agency database search, and a survey of regional experts involved in invasive species issues. 60 species were then chosen as subjects for the compilation of a series of species summaries detailing invasion and life history characteristics.

2.2.1. Literature Review

Project staff conducted a literature review focusing on the last 30 years of peer-reviewed journal articles and the last 15 years of government reports. Entries were annotated with abstracts when available and were arranged according to category: plants, animals, pathogens, and general information articles. The resulting annotated bibliography is more than 260 pages in length (see Appendix B). To facilitate the use of this extensive resource, the bibliography can be searched by species name or keyword via the Galveston Bay Invasive Species Checklist made possible by a partnership with the Central Southwest Gulf Coast Information Node (CSWGCIN) of the USGS National Biological Information Infrastructure (NBII).

2.2.2. Internet/Agency Database Search

Project staff identified and searched sources of online information and data describing invasive species. The search focused on species currently invading the Lower Galveston Bay Watershed and similar estuarine systems along the Gulf of Mexico coast from Texas to the Panhandle of Florida. Ten major sources of information used as the basis of the initial Lower Galveston Bay Watershed species list included:

- EPA Gulf of Mexico Program Inventory of Nonindigenous Aquatic Species Occurring in the Gulf of Mexico Region
- Gulf States Marine Fisheries Commission
- Invasivespecies.gov
- Invasive Species Specialist Group (ISSG) Global Invasive Species Database
- National Agricultural Pest Information System (NAPIS)
- NBII Invasive Species Node
- Smithsonian Environmental Research Center (SERC)
- Texas Parks and Wildlife Department (TPWD) Exotic Species Regulations
- USDA Plants Database
- USGS Nonindigenous Aquatic Species (NAS) Fact Sheet Collection/Database

2.2.3. Survey of Regional Experts

In Fall 2002, a survey was sent to 62 environmental professionals representing 27 federal, state, and local agencies, institutions of higher education, consulting firms, and non-governmental organizations to discern the existence of programs addressing invasive species in the Lower Galveston Bay Watershed. Requested information included geographic and taxonomic focus; type of efforts employed, and targeted species. A sample of the survey form can be viewed in Appendix C.

Of the 27 organizations surveyed, 14 (52%) responded. Ten of the respondents represented federal, state, or local agencies. Three institutions of higher education and one consulting firm also responded. See Table 3.1.1 for a summary of survey results.

2.3. Comparative Risk Assessment

A comparative risk assessment was performed through a series of four workshops held from April through August 2003 in Houston, Texas. Workshop participants represented local, state, and federal agencies; universities; non-governmental organizations; and others knowledgeable in the ecology and management of aquatic and terrestrial invasive species. Participating individuals were identified with the assistance of GBEP staff, the Galveston Bay Council, and the GBEP Invasive Species Working Group (ISWG).

2.3.1. Ecological Risk Assessment Criteria

A set of five risk criteria was initially developed by the invasive species project team enabling risk assessment participants to assign values for ecological and biodiversity impacts associated with specific invasive species. The risk criteria were based on the methodology developed by the Houston Environmental Foresight, Ecosystems Subpanel Risk Assessment (HARC, 1995).

Participants at the first workshop suggested the addition of a sixth criterion concerning impacts to human uses. Invasive species not only affect the biodiversity of an ecosystem, but can also affect direct human uses (e.g. fouling of commercial shrimping gear by sauerkraut grass), as well as indirect human uses (e.g. the impact of invasives on ecological services such as flood protection).

Workshop participants reviewed and modified the risk assessment criteria to ensure that criteria and scoring methods were clear in meaning and unambiguous to all. The criteria shown here and in Table 2.3.1 are the final criteria agreed to by workshop participants.

Six ecological risk criteria (see also Table 2.3.1) were used:

a) Likelihood: Likelihood of invasive species to impact Galveston Bay watershed at ecosystem level;
b) Severity: Potential site specific and ecosystem-wide impacts; expected percent loss of ecosystem biodiversity to impacts;
c) Location: Occurrence of invasive species relative to the Galveston Bay 5-county region;
d) Immediacy: Expected time until occurrence of invasive in the Galveston Bay 5-county region;
e) Irreversibility: Ability of natural and modified ecosystems to recover from damage after control/eradication of the invasive;
f) Impacts to human uses: Potential impact of invasive on human uses of Galveston Bay watershed.

Risk assessment participants assigned a score (1-5) for each of the six criteria for every species assessed. A score of 1 represented the least amount of risk associated with a particular criterion for a given species, while a score of 5 represented the greatest risk. For every species assessed, scores were summed across all six risk criteria. Those species with the highest risk assessment scores (maximum score possible = 30) were deemed as representing the greatest ecological risk to the Galveston Bay Watershed. Those species with the lowest scores (minimum score possible = 6) were deemed as representing the least ecological risk to the Galveston Bay Watershed.

Table 2.3.1. Six risk criteria utilized by Galveston Bay Invasive Species Risk Assessment participants to rank invasive species according to ecological risk. Each species assessed received a score of 1-5 for each criterion. Scores of 1 represented least risk. Scores of 5 denoted greatest risk. Risk scores for the six criteria were then summed for each assessed species to allow for an overall ranking. Highest possible score for a given species was 30 (highest risk). Least possible score for a given species was 6 (least risk).

<u>Likelihood of Watershed Impact</u> 1. Difficult to imagine 2. Anecdotal (likelihood of a watershed impact is possible based on anecdotal information) 3. Based on scientific literature (likelihood of a watershed impact is possible based on scientific literature) 4. Demonstrated in an equivalent ecosystem elsewhere 5. Demonstrated in the Galveston Bay 5-county region
<u>Potential Severity of Ecosystem Impact</u> 1. No potential site-specific impacts; not expected to be a contributor to significant ecosystem-wide modification; expect no loss of native biodiversity 2. Potential site specific impacts; expect modification of ecosystem or loss of native individuals; expect 1-5% loss of native biodiversity 3. Potential compromise of ecosystem or loss of native population; expect 5-10% loss of native biodiversity 4. Potential of strong compromise to ecosystem integrity or loss of native community; expect 10-50% loss of native biodiversity 5. Potential of strong contribution to or cause of fully degraded ecosystem; expect loss of ecosystem; expect >50% loss of native biodiversity
<u>Location/Area of Occurrence</u> 1. Not established in Gulf of Mexico states; not reported in Galveston Bay 5-county region; future threat 2. Established in Gulf of Mexico states; not reported in Galveston Bay 5-county region; future threat 3. Reported in Galveston Bay 5-county region; occurring in a single location 4. Reported in Galveston Bay 5-county region; occurring in multiple locations 5. Established in Galveston Bay 5-county region; occurring in all available habitat
<u>Immediacy of an Invasion</u> 1. Unknown 2. Low probability of occurrence in the Galveston Bay 5-county region in the near future 3. Medium probability of occurrence in the Galveston Bay 5-county region in the near future 4. High probability of occurrence in the Galveston Bay 5-county region in the near future 5. Present in the Galveston Bay 5-county region
<u>Irreversibility of Ecosystem Impact</u> 1. Recoverable in <1 year 2. Recoverable in 1-10 years 3. Recoverable in 10-50 years 4. Recoverable in 50-100 years 5. Unrecoverable (>100 years)
<u>Potential Impacts to Human Uses</u> 1. No potential site-specific impacts; not a contributor to impacts on human uses 2. Potential site specific impacts; contributes to some impacts on human uses 3. Potential of Some compromise to multiple human uses in Galveston Bay 5-county region 4. Strong compromise to multiple human uses in Galveston Bay 5-county region 5. Cause of complete degradation of multiple human uses in Galveston Bay 5-county region

2.3.2. Ecological Risk Assessment: Workshops 1, 2, and 3

The first workshop, held in April 2003, established the framework for the risk assessment process. Twenty-one participants discussed the nature of invasive versus introduced and exotic species, the methodology used to develop the initial species list, and the set of criteria to be used in the assessment.

Participants then reviewed the list of species developed by the project team (see section 2.2). Upon review, several new species were suggested for addition to the list while 34 species were unanimously identified for removal. Once chosen for removal, species were identified as NR (not ranked) and eliminated from the list of species to be assessed for ecological risk. Reasons for not assessing a species included: 1) long-established, ubiquitous invasives that would be nearly impossible to control or eradicate (e.g. European starling, house mouse, bermudagrass, etc.), 2) an exotic species with positive benefits to nature or society (e.g. European honeybee and many domesticated or agricultural mammals), 3) species expected to have a negligible impact on the Lower Galveston Bay watershed (e.g. Puerto Rican coqui and the sea lamprey), and 4) species with unknown impacts or life histories (e.g. Black sea jellyfish).

Prior to the workshop, the invasive species project team assigned each species to one of four "habitat" or thematic groupings: 1) Estuarine-marine, 2) Freshwater, 3) Terrestrial, and 4) Pathogens. The groupings were used to divide the species list into four sublists for consideration by corresponding workgroups. Workshop participants chose a workgroup to participate in according to their area of expertise. Each workgroup reviewed its species sublist to further select species for removal or identify new species for addition. It should be noted that due to a lack of available experts in the field of introduced microbiological pathogens, no workgroup for pathogens was formed. Please see Appendix D for the list habitat workgroup participants present at each workshop.

The second workshop was held in May 2003. Seventeen participants reviewed the species list and approved the additions and deletions proposed by participants at the April workshop. Species were also reassigned to other habitat workgroups as appropriate. Participants divided into habitat workgroups and initiated the ranking process.

A third risk assessment workshop was held in July 2003. Fourteen participants reviewed, slightly modified and approved changes to the ranking criteria proposed at an ad hoc criteria review meeting in June 2003. Workshop participants then continued the ranking process by reviewing rankings from the second workshop to ensure consistency with the modified criteria. The ecological risk ranking exercise was completed. Results are discussed in Section 3 below.

2.3.3. Management Risk Assessment: Workshop 4

A fourth risk assessment workshop was convened in August 2003. Participants were asked to review the ecological rankings from the previous workshop. The top 23 species were ranked according to five management criteria addressing feasibility of control or prevention, research, funding and staffing levels.

Five management criteria (see also Table 2.3.2) were used describing:

a) Feasibility of Prevention: Feasibility to prevent occurrence of the invasive in the Galveston Bay 5-county region;

b) Feasibility of Control and/or Eradication: Feasibility to control/eradicate invasive in the Galveston Bay 5-county region;

c) Status of Current Knowledge: Status of current knowledge; future research needs;

d) Status of Funding Levels to Prevent or Control: Status of current funding required to prevent or control invasive species; and

e) Status of Staffing Levels to Prevent or Control: Status of current skilled manpower/staffing required to prevent or control invasive species.

As with the ecological risk assessment, participants assigned a score (1-5) for each of the five management criteria for every species assessed. For some criteria only values of 1, 3, and 5 were assigned, as scores of 2 and 4 represented intermediate values that held no real meaning to risk assessment participants.

A score of 1 represented the least amount of risk associated with a particular criterion for a given species, while a score of 5 represented the greatest risk. For every species assessed, scores were summed across all five risk criteria. Those species with the highest risk assessment scores (maximum score possible = 25) were deemed as representing the greatest ecological risk to the Galveston Bay Watershed. Those species with the lowest scores (minimum score possible = 5) were deemed as representing the least ecological risk to the Galveston Bay Watershed.

Table 2.3.2. Management criteria utilized by Galveston Bay Invasive Species Risk Assessment participants to rank invasive species according to feasibility of prevention or control, knowledge, funding, and staffing levels. Each species assessed received a score of 1-5 for each criterion. Scores of 1 represented the best possible scenario. Scores of 5 denoted worst case scenarios. Management scores for the five criteria were then summed for each assessed species to allow for an overall ranking.

<u>Feasibility of Prevention *</u> 1. Possible to prevent invasion of the Galveston Bay 5-county region 2. n/a 3. Possible to slow invasion of the Galveston Bay 5-county region 4. n/a 5. Not possible to slow or prevent occurrence in the Galveston Bay 5-county region
<u>Feasibility of Control and/or Eradication **</u> 1. Effective methods for permanent eradication of invasive in the Galveston Bay 5-county region 2. Effective methods for temporary control of invasive in the Galveston Bay 5-county region 3. Effective methods for temporary, local control of invasive 4. Ineffective methods to control or eradicate invasive in the Galveston Bay 5-county region 5. No methods to control or eradicate invasive in the Galveston Bay 5-county region
<u>Status of Current Knowledge</u> 1. Very much is known about the invasive 2. n/a 3. Some is known about the invasive 4. n/a 5. Little is known about the invasive
<u>Status of Funding Levels to Prevent or Control</u> 1. Funding is adequate 2. n/a 3. Funding is minimal 4. n/a 5. Funding is insufficient
<u>Status of Staffing Levels to Prevent or Control</u> 1. Skilled manpower is adequate 2. n/a 3. Skilled manpower is minimal 4. n/a 5. Skilled manpower is insufficient

* This criterion was applicable to only those species that scored 1-2 in the *Location/Area of Occurrence* criterion from the ecological risk assessment (noted as not currently occurring in the Galveston Bay watershed; future threat).

** This criterion was applicable to only those species that scored 3-5 in the *Location/Area of Occurrence* criterion from the ecological risk assessment (noted as currently occurring in the Galveston Bay watershed).

3. Results

3.1. Information resources

3.1.1. Species Summaries

Species summaries were created for 60 invasive species (see Appendix E) and included the following subject areas:

- Common name
- Latin name
- Category (aquatic or terrestrial plant or animal, etc.)
- Place of origin
- Place of [US]introduction
- Date of [US]introduction
- Life history
- Growth and size
- Feeding habits and diet
- Habitat
- Attitude (aggressive, etc.)
- Physical description
- Management recommendations
- Reference information used for species summary

Creating species summaries for all 296 species on the original species list (see Appendix A) was not practical given project resources and time constraints. Instead, project staff chose a set of species for species summary creation based on the amount of information available in the literature. Species chosen for the summaries were selected prior to the risk assessment process so that they might be of use to the workshop participants. As a result, summaries exist for some species that did not rank highly in the ecological risk assessment process. Even so, those species summaries are still available as a deliverable of this project.

To facilitate the use of this resource, species summaries will be made available via the Galveston Bay Invasive Species Checklist through a partnership with the Central Southwest Gulf Coast information Node (CSWGCIN) of the USGS National Biological Information Infrastructure (NBII).

3.1.2. Annotated Bibliography

Project staff at the Environmental Institute of Houston (EIH) conducted a literature review. The literature review surveyed the last 30 years of published scientific literature and the last 15 years of reports by government agencies. An annotated bibliography (see Appendix B) was produced yielding more than 2,000 records. Organism-specific entries in the bibliography are categorized according to taxonomy.

The bibliography can be searched via the internet through the Galveston Bay Invasive Species Checklist, a partnership with the Central Southwest Gulf Coast information Node (CSWGCIN) of the USGS National Biological Information Infrastructure (NBII).

3.1.3. Results of the Survey of Invasive Species Professionals

Of the fourteen responding organizations, four reported that their efforts targeted the Lower Galveston Bay Watershed. Five programs were reported as having a statewide focus and five programs had no particular geographic focus. Of the five organizations stating that they conduct monitoring and assessment efforts, only one maintains an invasive species database. That same program was the only one to report itself as having geo-referenced data.

Seven responding organizations identified themselves as having programs focusing on the management and eradication of invasive species. Of those seven, six focus on the management and eradication of terrestrial plants, four on aquatic plants, two programs targeting mammals and one program focuses on finfish.

As seen in Table 2.2.1, the majority of programs responding targeted invasive terrestrial and aquatic vascular plants. Alternately, a few programs identified invasive finfish, invertebrates and mammals as targeted taxa. There were no programs identified as focusing on invasive pathogens, amphibians, or birds.

Four organizations identified themselves as conducting research in the field of invasive species. Their activities focused on terrestrial and aquatic plants, mammals, finfish and reptiles.

Four responding organizations identified themselves as conducting restoration efforts. All four identified Chinese tallow as a taxon of focus. This is not surprising in that Chinese tallow is arguably the most visible invasive species in the Lower Galveston Bay watershed.

Four organizations were identified as outreach organizations targeting aquatic and terrestrial plants and finfish.

Given the information supplied by the survey respondents, it must be made clear that the survey results are in no way representative of all invasive species related activities and programs taking place in the Lower Galveston Bay Watershed. However, it does appear to be indicative of the focus of most. The majority of programs in the Lower Galveston Bay Watershed target eradication and control of terrestrial plants while some attention is given to aquatic plants. Generally lacking in the Lower Galveston Bay Watershed are programs aimed at monitoring and assessment that maintain detailed geo-referenced data describing aquatic and terrestrial species invasions. Also lacking are large-scale public outreach/education efforts, programs restoring aquatic habitats degraded by invasive species, and general invasive species research related to invasive species-related impacts.

Table 3.1.1. Results of the 2002 Galveston Bay Invasive Species Survey

		No. of Organizations
Geographic Focus		
	Galveston Bay	4
	Statewide	5
	N/A	5
Databases Maintained		
	Yes	3
	No	11
Geo-referenced Data		
	Yes	1
	No	13
Effort Categories		
	Management/eradication	7
	Monitoring/assessment	5
	Outreach/education	4
	Research	4
	Restoration	4
	Regulation	2
	Cataloguing	1
	Other: Mitigation Response	1
Taxonomic Focus		
	Terrestrial Plants	10
	Aquatic Plants: Vascular	7
	Finfish	4
	Invertebrates/Shellfish	2
	Mammals	2
	Aquatic Plants: Phytoplankton	1
	Reptiles	1
	Amphibians	0
	Bacteria/Viruses	0
	Birds	0
Observed Species		
	Chinese tallow	7
	Water hyacinth	3
	N/A	3
	Alligator weed	2
	Giant Salvinia	2
	Grass carp	2
	Eurasian watermilfoil	1
	Feral hog	1
	Fire ants	1
	Giant reed	1
	Hydrilla	1
	Nutria	1
	Pacific white shrimp	1
	Pacu	1
	Salt cedar	1
	Tilapia	1
	None	1

3.2. Ranking of Ecological Risks

A primary objective of this project was to provide a comparison of a wide spectrum of invasive species according to the risk they represent to the health of Galveston Bay ecosystems and concomitantly to the users of those systems. Risk was quantified by assigning rank values to the criteria described above (Section 2.3). Lack of information on many species or unfamiliarity of the experts with their impacts contributed to an inability or unwillingness to rank many species on the original list. After three workshops and electronic submissions to the ranking process, we obtained complete rank scores for 84 species. Of the terrestrial species considered, 34 were of sufficient interest and concern to be ranked. Twenty-seven estuarine/marine species were ranked and 23 freshwater species. In some cases, the habitat was arbitrarily assigned to species reported from two or more of the habitat categories.

Of the 84 species ranked according to ecological risk, 15 were vertebrates, 33 were invertebrates, 34 were plants, and two constituted pathogens. Perceived risk for the taxonomic groups differed by habitat category. In the estuarine-marine habitat, the greatest risk was associated with invertebrates. Twenty-two invertebrate species were ranked, along with one vertebrate and four plant species. For the freshwater habitat, the highest risk was associated with species of finfish and plants. Ten vertebrates were ranked, four invertebrates, and nine plant species. Plants were by far perceived as the biggest threat to terrestrial habitats. Twenty-one plant species were ranked along with four vertebrates, seven invertebrates and two pathogens.

Table 3.2.1. Distribution of taxonomic groups by habitat classification for the species ranked by the experts in the invasive risk assessment.

Habitat	Vertebrate	Invertebrate	Plant	Pathogen
Estuarine/Marine	1	22	4	0
Freshwater	10	4	9	0
Terrestrial	4	7	21	2
Total	15	33	34	2

The ranking was accomplished by obtaining scores from the participating experts on the ecological risk criteria described in section 2.3.1 above. Each criterion had a high score of 5 points for a maximum total of 30 points possible for a species.

Overall, the highest score was 27 for Chinese tallow (*Triadica sebifera*). Thirty-five species received scores of 20 or more and are listed in Table 3.2.2. Due to ties of total scores, these 35 species were grouped into eight ranks with 1 being associated with the greatest risk to the Lower Galveston Bay watershed. Among the top eight ranks (35 highest ranked species), seven were ranked high due to their threat to the estuarine-marine ecosystem and associated human uses. Seventeen species were among the top eight ranks because they were viewed by risk assessment participants as serious threats to the freshwater ecosystems around Galveston Bay. Thirteen species viewed as serious threats to terrestrial ecosystems in the Lower Galveston Bay watershed were among the top eight ranks. See Appendix F for the complete list of overall rankings. Appendix G contains the ecological risk rankings of species according to individual risk criteria.

Table 3.2.2. Thirty five species with ecological risk scores of 20 or greater, their total scores, ranks and habitat group.

Species Name	Common Name	Sum	Rank	Habitat Group
Triadica sebifera	Chinese tallow tree, popcorn tree	27	1	TERR
Salvinia molesta	Giant Salvinia, kariba weed	26	2	FW
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	26	2	FW
Solenopsis invicta	Red imported fire ant	26	2	TERR
Eichhornia crassipes	Common water hyacinth	25	3	FW
Schinus terebinthifolius	Brazilian Pepper	25	3	TERR
Pomacea canaliculata	Channeled apple snail	24	4	FW, EST/MAR
Pistia stratiotes	Water lettuce	24	4	FW
Salvinia minima	Common Salvinia, water spangles	24	4	FW
Myocastor coypus	Nutria	23	5	FW, EST/MAR
Dreissena polymorpha	Zebra mussel	23	5	FW
Ctenopharyngodon idella	Grass carp	23	5	FW
Cyperus entrerianus	Boeckeler flat sedge, deep-rooted sedge	23	5	TERR
Tamarix ramosissima	Saltcedar, tamarisk	23	5	TERR
Ligustrum sinense	Chinese privet	22	6	TERR
Pueraria lobata	Kudzu, Japanese arrowroot	22	6	TERR
Eriocheir sinensis	Chinese mitten crab	21	7	EST/MAR
Zoobotryon verticillatum	Sauerkraut grass	21	7	EST/MAR
Oreochromis aureus	Blue tilapia	21	7	FW
Myriophyllum spicatum	Eurasian watermilfoil, spike watermilfoil	21	7	FW
Paspalum urvillei	Vaseygrass	21	7	TERR
Colocasia esculenta	Elephant ear, coco yam, Wild Taro	21	7	TERR
Apis mellifera scutellata	Africanized honeybee	21	7	TERR
Carcinus aestuarii	Mediterranean green crab	20	8	EST/MAR
Carcinus Maenas	European green crab	20	8	EST/MAR
Gymnodinium spp. (mikimotoi, etc)	Exotic red tide species	20	8	EST/MAR
Monopterus albus	Asian swamp eel	20	8	FW
Channa argus	Northern Snakehead	20	8	FW
Ipomoea aquatica	Water spinach, swamp morning-glory	20	8	FW
Lythrum salicaria	Purple loosestrife	20	8	FW
Alternanthera philoxeroides	Alligatorweed	20	8	FW
Corbicula fluminea	Asian clam	20	8	FW
Rosa bracteata	Macartney rose	20	8	TERR
Rosa multiflora	Multiflora rose	20	8	TERR
Cuscuta japonica	Japanese dodder	20	8	TERR

3.2.1. Likelihood of a Watershed Impact

As discussed in Section 2.3, this criterion is described as the likelihood of the invasive species to impact the Galveston Bay watershed at the ecosystem level. It is scored in terms of preponderance of evidence for an invasion. A recorded occurrence is not an invasion; there must be scientific evidence that this species has the capacity to reach abundance levels that will damage a local ecosystem. The 19 species that received a score of 5 (see Table 3.2.3) for this criterion have already demonstrated their capability to spread aggressively into local ecosystems. Species in this grouping are commonly described as nuisance species and subject to control efforts.

There are some species in this group that are unfamiliar to many people with knowledge of the biology of Galveston Bay. Sauerkraut grass is a Bryozoan that has reached epidemic abundances in some portions of Galveston Bay. Channeled apple snail is a relatively recent arrival that is spreading rapidly through some of the local bayous. Only in recent years have phycologists identified exotic species of red tide dinoflagellates, some of which were in the unusual red tide event that occurred in Galveston Bay in the summer of 2000.

Among the 84 species ranked for this criterion:

- 19 species scored 5 (Demonstrated in the Galveston Bay 5-county region)
- 25 species scored 4 (Demonstrated in an equivalent ecosystem elsewhere)
- 16 species scored 3 (Based on scientific literature)
- 14 species scored 2 (Anecdotal)
- 10 species scored 1 (Difficult to imagine)

More than half of the species ranked received their scores in association with their status as current invaders of Galveston Bay ecosystems or as invaders of some equivalent ecosystem. The *Likelihood* criterion contributed to a lower probability of potential invaders in remote locations being ranked highly as serious risks to Galveston Bay.

Table 3.2.3. The 19 species that received an ecological risk score of 5 under the *Likelihood* criterion. The species have already demonstrated their capability to spread aggressively into local ecosystems. Associated habitat group is also provided.

Species Name	Common Name	Score	Habitat
Triadica sebifera	Chinese tallow tree, popcorn tree	5	Terr
Solenopsis invicta	Red imported fire ant	5	Terr
Salvinia molesta	Giant Salvinia, kariba weed	5	FW
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	5	FW
Eichhornia crassipes	Common water hyacinth	5	FW
Pomacea canaliculata	Channeled apple snail	5	FW
Pistia stratiotes	Water lettuce	5	FW
Salvinia minima	Common Salvinia, water spangles	5	FW
Ctenopharyngodon idella	Grass carp	5	FW
Cyperus entrerianus	Deep-rooted sedge	5	Terr
Zoobotryon verticillatum	Sauerkraut grass	5	Est/Mar
Gymnodinium sp.	Exotic red tide species	5	Est/Mar
Myriophyllum spicatum	Eurasian watermilfoil	5	FW
Colocasia esculenta	Elephant ear, coco yam, Wild Taro	5	Terr
Oreochromis sp.	Hybrid tilapia	5	FW
Alternanthera philoxeroides	Alligatorweed	5	FW
Corbicula fluminea	Asian clam	5	FW
Cichlasoma cyanoguttatum	Rio Grande cichlid	5	FW
Hypostomus plecostomus	Suckermouth catfish, plecostomus	5	FW

3.2.2. Potential Severity of Ecosystem Impact

Severity is described by the degree to which invasive species damage large ecological systems. The Severity criterion has two components: loss of biodiversity and amount of ecosystem impacted. If the impact is localized to a single site, or if few native species are displaced across the ecosystem, then this criterion receives a low score. Few of the species evaluated for ecological risk had been documented to fully degrade an ecosystem.

Only seven species received the high score of 5 on this criterion (see Table 3.2.4). Six of the seven species are plants that form dense, near monocultures when they invade: Chinese tallow tree, giant Salvinia, Hydrilla, Brazilian pepper, kudzu and purple loosestrife. Asian swamp eel is the only animal considered to do equivalent damage to natural biodiversity.

The distribution of scores for severity over all 84 ranked species was almost normal:

- 7 species scored 5 (Potential of strong contribution to or cause of fully degraded ecosystem; expect loss of ecosystem; expect >50% loss of native biodiversity)
- 20 species scored 4 (Potential of strong compromise to ecosystem integrity or loss of native community; expect 10-50% loss of native biodiversity)
- 18 species scored 3 (Potential compromise of ecosystem or loss of native population; expect 5-10% loss of native biodiversity)
- 30 species scored 2 (Potential site specific impacts; expect modification of ecosystem or loss of native individuals; expect 1-5% loss of native biodiversity)
- 9 species scored 1 (No potential site-specific impacts; not expected to be a contributor to significant ecosystem-wide modification; expect no loss of native biodiversity)

Table 3.2.4. The seven species that received an ecological risk score of 5 under the *Severity* criterion. The species have already demonstrated their capability to spread aggressively into local ecosystems. Associated habitat group is also provided.

Species Name	**Common Name**	**Score**	**Habitat**
Triadica sebifera	Chinese tallow tree, popcorn tree	5	Terr
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	5	FW
Salvinia molesta	Giant Salvinia, kariba weed	5	FW
Schinus terebinthifolius	Brazilian Pepper	5	Terr
Pueraria lobata	Kudzu, Japanese arrowroot	5	Terr
Lythrum salicaria	Purple loosestrife	5	FW
Monopterus albus	Asian swamp eel	5	FW

3.2.3. Location/Area of Occurrence

This criterion distinguishes between those species that have invaded the Galveston Bay system and those with the potential to do so. High scores go to species that already impact multiple locations in the Lower Galveston Bay watershed. The scores produce a bimodal distribution. Among the 84 species ranked for this criterion:

- 14 species scored 5 (Established; occurring in all available habitat)
- 26 species scored 4 (Reported; occurring in multiple locations)
- 5 species scored 3 (Reported; occurring in a single location)
- 21 species scored 2 (Established in other Gulf of Mexico states; future threat)
- 18 species scored 1 (Not established in other Gulf of Mexico states; future threat)

Obviously, Chinese tallow and fire ant are among the species that scored 5, but also present on the list are deep-rooted sedge, Chinese privet, channeled apple snail, vaseygrass, three species of introduced bluestem grass, Johnson grass, nutria, feral cat, Asian clam and the Asian tiger mosquito (see Table 3.2.5).

Table 3.2.5. The 14 species that received an ecological risk score of 5 under the *Location/Area* criterion. Associated habitat group is also provided.

Species Name	Common Name	Score	Habitat
Triadica sebifera	Chinese tallow tree, popcorn tree	5	Terr
Solenopsis invicta	Red imported fire ant	5	Terr
Pomacea canaliculata	Channeled apple snail	5	FW
Cyperus entrerianus	Deep-rooted sedge	5	Terr
Myocastor coypus	Nutria	5	Est/Mar
Ligustrum sinense	Chinese privet	5	Terr
Paspalum urvillei	Vaseygrass	5	Terr
Corbicula fluminea	Asian clam	5	FW
Felis domesticus	Feral cat	5	Terr
Aedes albopictus	Asian tiger mosquito	5	Terr
Sorghum halepense	Johnsongrass	5	Terr
Bothriochloa ischaemum var. songarica	Yellow bluestem, King Ranch bluestem	5	Terr
Dichanthium annulatum	Kleberg bluestem	5	Terr
Dichanthium aristatum	Angleton bluestem	5	Terr

3.2.4. Immediacy of an Invasion

The expected time frame for the invasion is captured in the score for *Immediacy*. Low scores go to species that may never occur in the Lower Galveston Bay watershed and high scores go to those that are already present. The bias of this effort toward species that already threaten Galveston Bay is shown in the distribution of immediacy scores. Of the 84 species ranked:

- 44 species scored 5 (Present in the Galveston Bay 5-county region)
- 6 species scored 4 (High probability of occurrence in the near future)
- 11 species scored 3 (Medium probability of occurrence in the near future)
- 11 species scored 2 (Low probability of occurrence in the near future)
- 12 species scored 1 (Unknown)

17 species were assigned medium to high probability (scored 3 or 4) that they would invade the Galveston Bay watershed. The extra point (scores of 5) received by existing invasive species in this category is not sufficient to explain the preponderance of current invaders among the highest ranked species, but the correlation between high scores for immediacy and location made some contribution.

Table 3.2.6. The 44 species that received an ecological risk score of 5 under the *Immediacy* criterion. Associated habitat group is also provided.

Species Name	Common Name	Score	Habitat
Triadica sebifera	Chinese tallow tree, popcorn tree	5	Terr
Salvinia molesta	Giant Salvinia, kariba weed	5	FW
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	5	FW
Solenopsis invicta	Red imported fire ant	5	Terr
Eichhornia crassipes	Common water hyacinth	5	FW
Schinus terebinthifolius	Brazilian Pepper	5	Terr
Pomacea canaliculata	Channeled apple snail	5	FW
Pistia stratiotes	Water lettuce	5	FW
Salvinia minima	Common Salvinia, water spangles	5	FW
Cyperus entrerianus	Deep-rooted sedge	5	Terr
Myocastor coypus	Nutria	5	Est/Mar
Ctenopharyngodon idella	Grass carp	5	FW
Tamarix ramosissima	Saltcedar, tamarisk	5	Terr
Pueraria lobata, Pueraria Montana	Kudzu, Japanese arrowroot	5	Terr
Ligustrum sinense	Chinese privet	5	Terr
Cuscuta japonica	Japanese dodder	5	Terr
Apis mellifera scutellata	Africanized honeybee	5	Terr
Paspalum urvillei	Vaseygrass	5	Terr
Colocasia esculenta	Elephant ear, coco yam, Wild Taro	5	Terr
Zoobotryon verticillatum	Sauerkraut grass	5	Est/Mar
Oreochromis sp.	Hybrid tilapia	5	FW
Gymnodinium sp.	Exotic red tide species	5	Est/Mar
Myriophyllum spicatum	Eurasian watermilfoil	5	FW
Corbicula fluminea	Asian clam	5	FW
Rosa multiflora	Multiflora rose	5	Terr
Rosa bracteata	Macartney rose	5	Terr
Alternanthera philoxeroides	Alligatorweed	5	FW
Felis domesticus	Feral cat	5	Terr
Hypostomus plecostomus.	Suckermouth catfish, plecostomus	5	FW
Arundo donax	Giant reed, giant cane	5	Terr
Flavivirus sp.	West Nile Virus (WNV)	5	Terr
Coptotermes formosanus	Formosan subterranean termite	5	Terr
Ligustrum japonicum	Japanese ligustrum	5	Terr
Sus scrofa	Feral pig	5	Terr
Cichlasoma cyanoguttatum	Rio Grande cichlid	5	FW
Dichanthium aristatum	Angleton bluestem	5	Terr
Dichanthium annulatum	Kleberg bluestem	5	Terr
Bothriochloa ischaemum var. songarica	Yellow bluestem, King Ranch bluestem	5	Terr
Sorghum halepense	Johnsongrass	5	Terr
Lonicera japonica	Japanese honeysuckle	5	Terr
Aedes albopictus	Asian tiger mosquito	5	Terr
Wisteria sinensis	Chinese wisteria	5	Terr
Sturnus vulgaris	European Starling	5	Terr
Streptopelia decaocto	Eurasian collared dove	5	Terr

3.2.5. Irreversibility of Ecosystem Impact

The potential for recovery of ecosystems from the damage caused by the invader was a judgment call by the experts participating in this process. There were very few examples of the eradication of invasive species from invaded ecosystems on which to base this score. In many cases (48 of 84 ranked species receiving a score of 1 or 2), the experts believed that an ecosystem could recover in 1 to 10 years. Only nine species were scored as capable of damaging an ecosystem to the point at which it is unrecoverable, i.e. recovery in greater than 100 years (see Table 4.3.7). Six of the nine species that scored 5 for irreversibility were marine/estuarine invertebrates about which little is known. Three species of Ascidian were scored as 5 for irreversibility, but received scores of 1 or 2 on all other criteria. Three other species, a green alga, a polychaete and a jellyfish, received scores of 5 for irreversibility, but 1, 2 or 3 for other criteria.

To receive a score of 5 on this criterion, there must be a change in the ecosystem associated with invasion that cannot be restored in 100 years. There is no way to identify such an ecosystem change for these species, so their score appears to be related to fear of an unknown. Nutria, which can change the geomorphology of a marsh, and zebra mussel, which can change the plankton ecology of a lake or river, are given scores of 5 for this criterion, but they are easier to justify.

Of the 84 species ranked:

- 9 species scored 5 (Unrecoverable, i.e. >100 years)
- 12 species scored 4 (Recoverable in 50-100 years)
- 15 species scored 3 (Recoverable in 10-50 years)
- 41 species scored 2 (Recoverable in 1-10 years)
- 7 species scored 1 (Recoverable in <1 year)

The distribution of scores on this criterion suggests an optimism regarding ecological restoration following control. It is assumed that if the resources for control are available and employed to remove the invader, then the natural ecosystems will recover.

Table 3.2.7. The nine species that received an ecological risk score of 5 under the *Irreversibility* criterion. Associated habitat group is also provided.

Species Name	Common Name	Score	Habitat
Dreissena polymorpha	Zebra mussel	5	FW
Myocastor coypus	Nutria	5	Est/Mar
Drymonema dalmatinum	Peptol jellyfish	5	Est/Mar
Codium fragile tomentosoides	Dead man's fingers	5	Est/Mar
Daphnia lumholtzi	Water flea	5	FW
Boccardeilla ligerica	Polychaete worm	5	Est/Mar
Didemnum perlucidum	Ascidian	5	Est/Mar
Botryllus schlosseri	Ascidian	5	Est/Mar
Botryllus niger	Ascidian	5	Est/Mar

3.2.6. Potential Impacts to Human Uses

This criterion scored the degree to which an invading species impacts human uses of the ecosystem. Complete degradation of multiple uses received the highest score of 5 and was given to only six species (see Table 4.3.8). Four of these were aquatic plants that cover the water surface, fill the water column or are toxic to herbivores. Chinese mitten crab and zebra mussel are not yet present in the Lower Galveston Bay watershed, but received the highest ranking based on documentation of their impacts in similar ecological settings.

The mode in the distribution of scores for this criterion is 2, which translates into some impacts on human use at invaded sites. Of the 84 species ranked:

- 6 species scored 5 (Cause of complete degradation of multiple human uses)
- 11 species scored 4 (Strong compromise to multiple human uses)
- 23 species scored 3 (Potential of Some compromise to multiple human uses)
- 30 species scored 2 (Potential site specific impacts; contributes to some impacts on human uses)
- 14 species scored 1 (No potential site-specific impacts; not a contributor to impacts on human uses)

Thirty species received the score of 2 and 23 species were scored as 3 for "some compromise to multiple human uses." The experts involved in this risk assessment believed that 83% of the species ranked have caused or could cause some impacts on human uses to a complete degradation of uses. Clearly the preponderant view is that most invasive species are economically as well as ecologically harmful.

Table 3.2.8. The six species that received an ecological risk score of 5 under the *Impacts to Human Uses* criterion. Associated habitat group is also provided.

Species Name	Common Name	Score	Habitat
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	5	FW
Salvinia molesta	Giant Salvinia, kariba weed	5	FW
Eichhornia crassipes	Common water hyacinth	5	FW
Dreissena polymorpha	Zebra mussel	5	FW
Eriocheir sinensis	Chinese mitten crab	5	Est/Mar
Caulerpa taxifolia	Caulerpa seaweed	5	Est/Mar

3.2.7. Relationship Among Ecological Risk Criteria

The criteria were scored using an ordinal scale that can be used in nonparametric statistical analyses. One such analysis is called Kendall's tau, a nonparametric measure of association for ordinal or ranked variables that take ties into account. The sign of the coefficient indicates the direction of the relationship, and its absolute value indicates the strength, with larger absolute values indicating stronger relationships. In other words, Kendall's tau values range from a perfect direct relationship at +1.0, a perfect inverse relationship at -1.0, and no relationship 0.0.

Several of the pairwise relationships between criteria exhibit significant positive associations:

- Location and Immediacy (tau = 0.65, $p < 0.001$)
- Likelihood and Severity (tau = 0.47, $p < 0.001$)
- Likelihood and Immediacy (tau = 0.31, $p < 0.001$)
- Likelihood and Impact on Human Uses (tau = 0.39, $p < 0.001$)
- Severity and Impact on Human Uses (tau = 0.49, $p < 0.001$)

The irreversibility criterion exhibits a pattern of negative correlation with all of the other criteria and the negative relationship with location (tau = -0.27, $p = 0.001$) and immediacy (tau = -0.31, $p < 0.001$) are significant.

Table 3.2.9. Pairwise relationships between ecological risk criteria using Kendall's tau, a nonparametric measure of association for ordinal or ranked variables.

Criteria	**Severity**	**Location**	**Immediacy**	**Irreversibility**	**Human Uses**
Likelihood	0.47 <0.001	0.19 0.024	0.31 <0.001	-0.19 0.020	0.39 <0.001
Severity		0.05 0.558	0.12 0.146	-0.02 0.787	0.49 <0.001
Location			0.65 <0.001	-0.27 0.001	0.00 0.987
Immediacy				-0.31 <0.001	0.07 0.36
Irreversibility					-0.18 0.031

Scores for likelihood of an invasive to impact the Lower Galveston Bay watershed at the ecosystem level show significant positive correlations with severity, immediacy and impacts on human uses. In the first case, the two criteria are similar because likelihood is described in terms of impact on ecosystems, while severity is described in terms of biodiversity loss. Obviously there is a relationship between biodiversity and ecosystem structure. Immediacy is scored according to the expected time frame of occurrence in the region. High scores represent species that have become established and spread. Invaders that are already established also receive high likelihood scores. The relationship between likelihood and impacts on human uses appears to be based on the association between species that are unlikely to invade and the tendency to score them as having no or few impacts on human uses in the Galveston Bay watershed.

3.3 Ranking of Management Risk

A second objective of this project involved the ranking of invasive species according to a set of management criteria. The management criteria were designed to assess the experts' perceived risk based on the following criteria: feasibility of management strategies, the state of current knowledge, and state of funding and staffing resources pertaining to the prevention and control of invasive species in the Lower Galveston Bay watershed. Of the 84 species ranked in the ecological risk assessment, the top 23 species were scored according to the five management criteria (see also Section 2.3.3):

- Feasibility of Prevention
- Feasibility of Control and/or Eradication:
- Status of Current Knowledge:

- Status of Funding Levels to Prevent or Control
- Status of Staffing Levels to Prevent or Control

Species were scored for each criterion on a scale of 1-5 with 1 representing least risk and 5 representing greatest risk. Scores for each criterion were summed to yield an overall management risk score (see Table 3.3.1). Similar to the ecological risk assessment, the unknown played a large role in the results. Overall, species studied in the watershed for a long period of time tended to score lower, equating to less perceived risk with regards to available management strategies, knowledge, funding, staffing, and research (e.g. Hydrilla, water hyacinth, nutria, Africanized honeybee). Species identified as future threats (the Chinese mitten crab and zebra mussel) and species recently identified in the watershed (channeled apple snail and sauerkraut grass) scored high overall equating to greater perceived management risk.

Table 3.3.1. Overall rankings of invasive species according to management criteria risk analysis. Associated habitat group is also provided.

Genus Species	Common Name	Score	Habitat
Zoobotryon verticillatum	Sauerkraut grass	20	EST/MAR
Pomacea canaliculata	Channeled apple snail	18	FW
Paspalum urvillei	Vaseygrass	17	TERR
Eriocheir sinensis	Chinese mitten Crab	16	EST/MAR
Cyperus entrerianus	Deep-rooted sedge	16	TERR
Dreissena polymorpha	Zebra mussel	16	FW
Myriophyllum spicatum	Eurasian watermilfoil	15	FW
Ctenopharyngodon idella	Grass carp	13	FW
Schinus terebinthifolius	Brazilian Pepper	12	TERR
Ligustrum sinense	Chinese privet	12	TERR
Tamarix ramosissima	Saltcedar, tamarisk	12	TERR
Salvinia minima	Common Salvinia, water spangles	11	FW
Colocasia esculenta	Elephant ear, coco yam, Wild Taro	11	TERR
Salvinia molesta	Giant Salvinia, kariba weed	11	FW
Oreochromis sp.	Hybrid tilapia	11	FW
Pueraria lobata	Kudzu, Japanese arrowroot	11	TERR
Solenopsis invicta	Red imported fire ant	11	TERR
Apis mellifera scutellata	Africanized honeybee	10	TERR
Triadica sebifera	Chinese tallow tree, popcorn tree	10	TERR
Myocastor coypus	Nutria	9	FW
Eichhornia crassipes	Common water hyacinth	8	FW
Pistia stratiotes	Water lettuce	8	FW
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	7	FW

3.3.1. Feasibility of Prevention

Of the 23 species ranked for management risk, the Chinese mitten crab (*Eriocheir sinensis*) and the zebra mussel (*Dreissena polymorpha*) were identified as future threats to the Galveston Bay watershed and were the only species scored under this criterion. The remaining 21 species were identified as current threats and were ranked according to the *Feasibility of Control* criterion.

The Chinese mitten crab scored a 3 under this criterion. Experts believed that current prevention techniques have a fairly good probability of slowing the invasion in the Lower Galveston Bay watershed, but might not be able to prevent an invasion altogether. The Zebra mussel scored a 5 under this criterion, meaning that experts are more pessimistic about the prevention of an invasion by this species given current prevention strategies. It should be noted that the Chinese mitten crab and the zebra mussel are by no means the only species that should be targeted by prevention efforts in the Lower Galveston Bay Watershed. Forty species were identified as possible targets for prevention efforts (see Appendix H).

3.3.2. Feasibility of Control and/or Eradication

Twenty one species were ranked under this criterion because of their current existence in the Lower Galveston Bay watershed. Experts identified the channeled apple snail and sauerkraut grass as having the least likelihood for control and/or eradication. Both of these species are relatively newly identified invaders of the Lower Galveston Bay watershed.

Table 3.3.2. Twenty one invasives species ranked according to feasibility of control and /or eradication given current techniques. Scores range from 1-5, with 1 representing the greatest feasibility for control and/or eradication and 5 representing the least feasibility for control and/or eradication, or greatest risk. Associated habitat group is also provided.

Genus Species	Common Name	Score	Habitat
Pomacea canaliculata	Channeled apple snail	5	FW
Zoobotryon verticillatum	Sauerkraut grass	5	EST/MAR
Colocasia esculenta	Elephant ear, coco yam, Wild Taro	4	TERR
Myriophyllum spicatum	Eurasian watermilfoil	4	FW
Ctenopharyngodon idella	Grass carp	4	FW
Oreochromis sp.	Hybrid tilapia	4	FW
Pueraria lobata	Kudzu, Japanese arrowroot	4	TERR
Myocastor coypus	Nutria	4	FW
Solenopsis invicta	Red imported fire ant	4	TERR
Paspalum urvillei	Vaseygrass	4	TERR
Apis mellifera scutellata	Africanized honeybee	3	TERR
Ligustrum sinense	Chinese privet	3	TERR
Triadica sebifera	Chinese tallow tree, popcorn tree	3	TERR
Eichhornia crassipes	Common water hyacinth	3	FW
Cyperus entrerianus	Deep-rooted sedge	3	TERR
Pistia stratiotes	Water lettuce	3	FW
Salvinia minima	Common Salvinia, water spangles	2	FW
Salvinia molesta	Giant Salvinia, kariba weed	2	FW
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	2	FW
Schinus terebinthifolius	Brazilian Pepper	1	TERR
Tamarix ramosissima	Saltcedar, tamarisk	1	TERR

3.3.3. Status of Current Knowledge

Risk assessment participants ranked the 23 invasive species according to the state of current knowledge. As seen in Table 3.3.3, eleven species received the lowest score of 1 meaning that ample information can be found regarding these species. Some species such as the zebra mussel, red imported fire ant, Hydrilla, Chinese tallow, and Africanized honeybee have been the subjects of numerous research studies over the years and much is known about their ecological impacts and control and prevention techniques.

Eleven species received intermediate scores of 3, meaning that the risk assessment participants felt that there is some information in the literature regarding species impacts and management strategies. Species in this category included vaseygrass, saltcedar, giant Salvinia, elephant ear, deep-rooted sedge, Chinese mitten crab, and channeled apple snail. One species, the Bryozoan sauerkraut grass, scored the highest under this criterion. It represents a high perceived risk with regards to status of current knowledge. Very little is known about the impacts of this species on Galveston Bay ecosystems.

Table 3.3.3. Twenty three invasives species ranked according to status of current knowledge. Scores range from 1-5, with 5 representing those species for which little research has been undertaken and a score of 1 representing species with an adequate knowledge base. Associated habitat group is also provided.

Genus species	Common Name	Score	Habitat
Zoobotryon verticillatum	Sauerkraut grass	5	EST/MAR
Pomacea canaliculata	Channeled apple snail	3	FW
Eriocheir sinensis	Chinese mitten Crab	3	EST/MAR
Ligustrum sinense	Chinese privet	3	TERR
Salvinia minima	Common Salvinia, water spangles	3	FW
Cyperus entrerianus	Deep-rooted sedge	3	TERR
Colocasia esculenta	Elephant ear, coco yam, Wild Taro	3	TERR
Myriophyllum spicatum	Eurasian watermilfoil	3	FW
Salvinia molesta	Giant Salvinia, kariba weed	3	FW
Pueraria lobata	Kudzu, Japanese arrowroot	3	TERR
Tamarix ramosissima	Saltcedar, tamarisk	3	TERR
Paspalum urvillei	Vaseygrass	3	TERR
Apis mellifera scutellata	Africanized honeybee	1	TERR
Schinus terebinthifolius	Brazilian Pepper	1	TERR
Triadica sebifera	Chinese tallow tree, popcorn tree	1	TERR
Eichhornia crassipes	Common water hyacinth	1	FW
Ctenopharyngodon idella	Grass carp	1	FW
Oreochromis sp.	Hybrid tilapia	1	FW
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	1	FW
Myocastor coypus	Nutria	1	FW
Solenopsis invicta	Red imported fire ant	1	TERR
Pistia stratiotes	Water lettuce	1	FW
Dreissena polymorpha	Zebra mussel	1	FW

3.3.4. Status of Funding Levels to Prevent or Control

Risk assessment participants ranked the 23 invasive species according to current funding levels to prevent or control invasions in the Lower Galveston Bay watershed. Of the 23 species, none were identified as receiving adequate funding (see Table 3.3.4). Eleven species were ranked as receiving minimal funding while twelve species were identified as receiving insufficient funding to prevent or control.

Table 3.3.4. Twenty three invasives species ranked according to status of funding levels to prevent or control. Scores range from 1-5, with 5 representing those species targeted with insufficient funding and a score of 3 representing species targeted with minimal funding. No species were identified as receiving adequate funding for research or management. Associated habitat group is also provided.

Genus species	Common Name	Score	Habitat
Schinus terebinthifolius	Brazilian Pepper	5	TERR
Pomacea canaliculata	Channeled apple snail	5	FW
Eriocheir sinensis	Chinese mitten Crab	5	EST/MAR
Ligustrum sinense	Chinese privet	5	TERR
Triadica sebifera	Chinese tallow tree, popcorn tree	5	TERR
Cyperus entrerianus	Deep-rooted sedge	5	TERR
Oreochromis sp.	Hybrid tilapia	5	FW
Solenopsis invicta	Red imported fire ant	5	TERR
Tamarix ramosissima	Saltcedar, tamarisk	5	TERR
Zoobotryon verticillatum	Sauerkraut grass	5	EST/MAR
Paspalum urvillei	Vaseygrass	5	TERR
Dreissena polymorpha	Zebra mussel	5	FW
Apis mellifera scutellata	Africanized honeybee	3	TERR
Salvinia minima	Common Salvinia, water spangles	3	FW
Eichhornia crassipes	Common water hyacinth	3	FW
Colocasia esculenta	Elephant ear, coco yam, Wild Taro	3	TERR
Myriophyllum spicatum	Eurasian watermilfoil	3	FW
Salvinia molesta	Giant Salvinia, kariba weed	3	FW
Ctenopharyngodon idella	Grass carp	3	FW
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	3	FW
Pueraria lobata	Kudzu, Japanese arrowroot	3	TERR
Myocastor coypus	Nutria	3	FW
Pistia stratiotes	Water lettuce	3	FW

3.3.5. Status of Staffing Levels to Prevent or Control

Risk assessment participants ranked the 23 invasive species according to current staffing resources devoted to prevention and control in the Lower Galveston Bay watershed. Of the 23 species, ten were identified as having adequate staffing resources (see Table 3.3.5). Four species were ranked as having minimal manpower to carry out prevention and control efforts. Nine species were identified as having insufficient staffing resources to prevent or control invasion.

Table 3.3.5. Twenty three invasives species ranked according to status of staffing levels to prevent or control. Scores range from 1-5, with 5 representing those species targeted with insufficient staffing resources and a score of 1 representing species targeted by sufficient staffing levels. Associated habitat group is also provided.

Genus Species	Common Name	Score	Habitat
Schinus terebinthifolius	Brazilian Pepper	5	TERR
Pomacea canaliculata	Channeled apple snail	5	FW
Eriocheir sinensis	Chinese mitten Crab	5	EST/MAR
Cyperus entrerianus	Deep-rooted sedge	5	TERR
Myriophyllum spicatum	Eurasian watermilfoil	5	FW
Ctenopharyngodon idella	Grass carp	5	FW
Zoobotryon verticillatum	Sauerkraut grass	5	EST/MAR
Paspalum urvillei	Vaseygrass	5	TERR
Dreissena polymorpha	Zebra mussel	5	FW
Apis mellifera scutellata	Africanized honeybee	3	TERR
Salvinia minima	Common Salvinia, water spangles	3	FW
Salvinia molesta	Giant Salvinia, kariba weed	3	FW
Tamarix ramosissima	Saltcedar, tamarisk	3	TERR
Ligustrum sinense	Chinese privet	1	TERR
Triadica sebifera	Chinese tallow tree, popcorn tree	1	TERR
Eichhornia crassipes	Common water hyacinth	1	FW
Colocasia esculenta	Elephant ear, coco yam, Wild Taro	1	TERR
Oreochromis sp.	Hybrid tilapia	1	FW
Hydrilla verticillata	Hydrilla, waterthyme, Florida elodea	1	FW
Pueraria lobata	Kudzu, Japanese arrowroot	1	TERR
Myocastor coypus	Nutria	1	FW
Solenopsis invicta	Red imported fire ant	1	TERR
Pistia stratiotes	Water lettuce	1	FW

3.4. Control and Prevention

3.4.1. Control

The survival or reproduction of invasive species can be affected by chemical, physical or mechanical techniques. Efforts to control invaders are usually limited to one or two of the methods. The success of efforts to control invaders is related to the ability to treat the population of invaders, the effectiveness of the treatment and the ability to limit the impact of the treatment to invaders only. The tendency of water to disperse chemical control agents leads to a greater likelihood of unintended toxic consequences when chemical agents are used to control aquatic invasive species versus terrestrial invasives. Only a few aquatic plants have approved chemical control techniques. Even fewer aquatic animals have preferred control methods involving application of toxic chemicals.

Physical removal methods are applied in terrestrial and aquatic environments, but the techniques differ greatly. Mechanical methods are primarily based on killing or capture of animals (e.g. feral hog) and cutting or removal of plants (e.g. Chinese tallow or Hydrilla). Fire is a preferred control agent for some terrestrial invasive plants, especially those invading prairie ecosystems; but is not applicable to aquatic invaders. The lowering of water depth is used to control aquatic invasive plants and aquatic animals. Mechanical control is applicable to both types of environment, but it can be very labor intensive and expensive.

Large-scale control efforts are often based on chemical technologies. This type of control technology is difficult to apply in the aquatic environment. The result of this problem is a more limited variety of control technology for aquatic organisms, especially aquatic animals. For example, channeled apple snail could be more easily controlled by application of a molluscicide if it occurred in terrestrial ecosystems. Use of a molluscicide in the aquatic systems where they occur will result in death of untargeted, native molluscs.

Control of invasive species has a long history, particularly in agricultural practices. Control technologies based on chemical treatments, mechanical removal, biological control and management practices have all been developed, tested and implemented. Lethal control methods are well known for fire ants, Chinese tallow, water hyacinth, and many others considered high risk by this assessment. However, many of the control methods are also harmful to similar native species. Thus when high-risk species occur in public waters or in public parks and reserves, some control practices may be precluded.

The problem of harm to native species in the same community explains why some invaders have no accepted control method. For example, grass carp could be controlled by any poison lethal to large fish, but such a method is not acceptable for public waters. One exception to this precaution is mosquito control. The Asian tiger mosquito is controlled by insecticides that are lethal to native mosquitoes as well. A general policy of spraying for mosquito control is justified by human health concerns, but it results in depauperate native insect fauna in areas subject to mosquito control.

Of the 84 invasive species ranked by participants in the Lower Galveston Bay watershed risk assessment process, a little over half (52 percent) were identified as target species for control strategies:

- 33 percent (28 species) from terrestrial habitats
- 15 percent (13 species) from freshwater habitats
- percent (3 species) from estuarine-marine habitats

3.4.2. Prevention

Prevention strategies require an entirely different planning process than do control strategies. Control methods can be tailored to the habitat, behavior and physiology of the individual species, whereas, prevention methods will seldom be developed for individual species, although zebra mussel is an exception. Prevention methods will apply to species that share a method of transport from one location to another. Prevention means interrupting the dispersal process. For example, ballast water transport of estuarine and marine species larvae can be prevented by treating the ballast water in a manner lethal to all organisms. Transport of human pathogens, such as the SARS virus, may be interdicted by quarantines and other public health measures that are simultaneously effective for multiple pathogens. In some cases, specific species may be targeted for prevention, as in the case of prohibited lists for importation, but the methodology of customs inspections is not species specific.

The list of high-risk species for the estuarine and marine habitats contains the largest proportion of species targeted for prevention (see Appendix H). Some of these potential invaders are close enough to Galveston Bay to be transported in water currents, in which case, prevention would be extremely difficult. The principal methods of prevention for estuarine and marine species involve regulation of ballast water, aquaculture and live seafood markets. In each case, there are models of best management practices that could be designed for the target species identified by this project.

Of the 84 invasive species ranked by participants in the Lower Galveston Bay watershed risk assessment process, a nearly half (48 percent) were identified as target species for prevention strategies:

- 29 percent (24 species) from estuarine-marine habitats
- 12 percent (10 species) from freshwater habitats
- 7 percent (6 species) from terrestrial habitats

4. Discussion

4.1. Problems with Criteria Overlap or Confusion

Ideally each criterion should provide an independent score of a parameter of risk from invasion by exotic species that is independent of all other criterion. Similarly each criterion should be interpreted by all participants in the same way and employed unambiguously in the process. These expectations were not met in this process despite interim efforts at modifying the criteria to respond to concerns of experts involved in the process. Despite our failure to achieve complete independence among and precise use of criteria, the risk assessment did yield an important encapsulation of expert opinion on the challenge facing the Galveston Bay watershed in the form of current and future invasions by exotic species.

Specific items of confusion or lack of independence include the equivalency of the highest score for the criteria location and immediacy. A species that is already established earns the same score for both. Also, descriptions of likelihood and severity both involve impacts to the receiving ecosystem and are significantly correlated. Evaluation of invasive species for severity of impact was complicated by the difficulty encountered in distinguishing between site-specific and ecosystem wide impacts. Observations of impacts are site specific and few ecosystem wide assessments have been done.

There was also difficulty in separating severity from impact on human uses. Severity was intended to assess impacts on the biological community independent of human involvement, while impact on human uses should have been independent of impacts on species not exploited by humans. However, as human observers, the participants tended to think first of their interaction with the ecosystem impacted and secondarily of the impacts from the perspective of the biological community. This is consistent with the way invasive species are brought to the attention of management agencies. The greatest attention is devoted to species that degrade human use of an ecosystem.

Finally, irreversibility was intended to provide an assessment of the effect of invasion on the evolutionary integrity of an ecosystem. Experts were asked to imagine that an invasive species had been eradicated from an ecosystem in which it was fully established. Then they were to predict the amount of time required for the ecosystem to fully recover its pre-invasion biological integrity. This is difficult to do for aquatic systems that have not been studied for ecological succession patterns. The recovery patterns of grasslands and forests are reasonably well known, but this is not true for bayous and estuaries. Scoring of irreversibility for terrestrial species is likely to be more accurate than the scoring of this criterion for freshwater and estuarine species.

4.2. Information Gaps and Impact on Rankings

Lack of information had a serious impact on the risk assessment in two ways. First, there was a tendency to demote species about which little was known from the group of species retained for the complete risk assessment. This was particularly true of pathogens. None of the volunteer experts had a background in microbiology or public health. Therefore, no one felt that they could properly assess the risk of pathogenic bacteria and viruses, with the exception of West Nile virus. This exception is due to the media attention focused on this newly invading human pathogen.

The collective knowledge of the group of experts was greatest for invasive species that already exist in the Galveston Bay watershed. Of the 84 species ranked, 52% are already present in the Galveston Bay system. In addition to poorly understood species, invaders that are established in the region, but are associated with no major ecological impacts were demoted to the unranked list (see Appendix I).

Second, a lack of information combined with invasion of a fundamental niche in an ecosystem yielded a fear of impacts that was expressed in high rankings for severity or irreversibility. This is best expressed in the rankings given to the three species of Ascidian. These species were unknown to all but two of the experts involved in the assessment, but when the potential impacts were described to the group evaluating estuarine and marine species, they received high scores for irreversibility.

4.3. Absence of Monitoring Programs

The list of existing and potential invaders from which the risk assessment operated was compiled in a systematic way, but was not based on data from scientific monitoring programs. Invaders that have become established are reported to management agencies if they create a problem, have been advertised as nuisance species, or were documented in a scientific study.

Potential invaders should include the entire biodiversity of other regions with environmental regimes similar in some way to the Galveston Bay watershed. However, only those species known to invade estuarine, freshwater and terrestrial ecosystems in the temperate and subtropical regions of North America were targeted for consideration. No data was found on monitoring of potential vectors to the Texas coast for rate of transfer of exotic species. No data was found on surveys of biodiversity in the Galveston Bay region intended to detect newly invading species.

The Coastal Fisheries Division of TPWD does conduct a fisheries monitoring program that can detect exotic macroinvertebrates and fish when they are captured. TPWD Coastal Fisheries is also involved in a pilot aquatic invasive species monitoring study of several area bayous (see Section 1.4). The Texas Commission on Environmental Quality (TCEQ) is conducting analyses of benthic communities for water quality purposes. These evaluations could provide early detection of exotic benthic species. However, no agency regularly monitors the plankton, insects, fungi, and many other small or non-commercial taxa to detect newly invading exotic species. Invaders of these types will be noted only after they have become a problem in most cases.

4.4. Unpredictability of Potential Invaders

There is no scientific theory capable of predicting successful invasions by exotic species. Successful invasions are not dependent on matching the habitat characteristics or climate between a species native range and introduced locations. Species with large native ranges have some advantage upon introduction into new habitats, but still often fail to become established (Pimm, 1991).

There was much discussion in the risk assessment workshops about the probability of a particular species reaching Galveston Bay and becoming established. Knowledgeable people had distinct perspectives on the viability of various transport mechanisms. These differences probably diminished the rankings of potential invaders in many cases. Despite the unpredictability of any single invasion, there was general agreement that the process of invasion has a high probability. We cannot identify the source of the next invasion or predict its timetable, but we can say with certainty that there will be a continuing series of invasions.

4.5. Invasion Probability, Control and Prevention

4.5.1. Invasion Probability

The probability of a successful invasion by an exotic species is based on many ecological factors including the:

- Similarity between the niche requirements of the introduced organism and the attributes of the environment into which the organism is introduced;
- Ability of the organism to adapt to varying conditions;
- Rate at which the organism reaches maturity and ability to reproduce (fecundity);
- Lack of natural competitors, consumers, and parasites in the invaded ecosystem;
- Frequency of repetitive introductions (The more a species is introduced to the same ecosystem, the greater its chances of establishment); and
- Condition of the ecosystem being invaded (If an ecosystem is stressed, the probability of invasion increases).

While all of the factors mentioned above play important roles in the establishment of nonindigenous species, the most successful introduced organisms often have the ability to adapt as necessary to survive in their new environment. For example, a marine aquatic organism has a very low probability of successfully invading a freshwater habitat and zero probability of successfully invading a terrestrial habitat. However, a look at the history of fairly recent invasions shows that the match between a species' native and introduced environments need not be exact. For example, the zebra mussel (*Dreissena polymorpha*) is tolerant of a wide range of depths, temperatures, and salinities. Native to the Black, Caspian and Azov Seas of Eurasia, the zebra mussel established itself in most of the freshwater habitats of Great Britain between 1820 and 1920. It was first documented in the U.S. in the Great Lakes in the 1980's, and is currently distributed along the Mississippi River into Louisiana and in the Mohawk and Hudson River systems of the northeastern U.S.

The probability of success for an exotic invader is also related to the ability to reach maturity and reproduce quickly, thus producing a population with a low probability of extinction. Invaders with high fecundity are usually more successful than similarly introduced species with lower reproductive potential. If reproductive rates are high and overall the number of new offspring exceed deaths; then an invading species has a good chance of securing a foothold in the new habitat.

Competition, predation, and parasitism also influence the likelihood of an invasion being successful in a new environment. Diverse food webs consisting of many species exhibit high levels of competition among species for resources. A diverse food web also has a greater chance of containing species to prey upon or parasitize the invasive. If a new species enters an ecosystem with a complex, mature food web, there is a greater probability that the invasive will not thrive than if introduced into a simple food web.

Very often in areas impacted by humans and development, the environments that result are simple food webs. Agricultural, suburban, and urban landscapes are good examples of modified or disturbed habitats where ecological diversity and competition for resources is low while the frequency of invasive species is high. A lower percentage of individuals represent invasive species in natural ecosystems, e.g. prairie or hardwood forest.

The relationship between a low level of competition and a high probability of successful invasion can be seen in the frequency of invasive species in freshwater reservoirs versus coastal bays. Reservoirs are simple, artificial ecosystems that have both the natural riverine species and introduced species in them. Introduced predators often dominate the system and invasions appear to be relatively easy. In contrast, bays have often been subject to introductions, e.g. plankton in ballast water, but are usually dominated by the natural fauna. In general, freshwater introductions have a higher probability of success than marine introductions.

Factors in the probability of invasion success can be used to understand the difference among terrestrial, freshwater and estuarine habitats regarding frequency of invasive species. Terrestrial ecosystems in the U.S. have been modified by human activity to a much greater degree than aquatic ecosystems. The majority of the land area is used for agriculture, forestry or residential purposes. Each of these activities is accompanied by introductions, either intentional or accidental. Agriculture is based solely on introduced species, most of which were imported with a variety of exotic pests and hitchhikers. Residential and commercial development is accompanied by horticultural activity that introduces exotic plants with associated pest species. Thus terrestrial invasions tend to correlate to ecosystem disturbance and simplification, i.e. lower competition. Many of the plants and animals associated with human activities have already demonstrated their adaptation to habitats shared with humans.

Freshwater and marine habitats are less disturbed or artificial than many of the invaded terrestrial habitats. Freshwater ecosystems have been modified by dams in many cases and many reservoirs have received intentional introductions for recreational fishing. Freshwater ecosystems have simpler food webs than marine ecosystems, thus an exotic invader is likely to face less competition for resources. Many aquatic species that are cultured for food or as pets find their way into freshwater ecosystems. Some of these become established as invaders. This is true of the tributaries of Galveston Bay. While some estuarine ecosystems have significant populations of multiple invaders (e.g. San Francisco Bay, Chesapeake Bay), Galveston Bay seems to have fewer problematic invasive species.

The degree to which a habitat is impacted by invasive species is a result of the frequency with which exotic species are introduced, the rate at which introduced species adapt and survive, and the rate at which they reproduce and spread. In the Lower Galveston Bay watershed, the greatest number of invasive species has been noted in terrestrial habitats. Fewer invasive species are noted in freshwater habitats, but the area of those habitats is considerably less than the area of terrestrial habitats in the watershed. Many fewer invasive species are listed for the estuarine habitat. This could be the result of fewer introductions, of a lower success rate for introductions due to lower rates of survival and reproduction, of lower visibility and less monitoring, or a combination of these. For whatever reason, invasive species are currently having less impact on Galveston Bay than on the prairies, woodlands and bayous in the adjoining watershed.

4.5.2. Balancing Control and Prevention

The introduction of new species has occurred over evolutionary time as a result of transport by storms, rafts of vegetation, etc. In the last 600 years, anthropogenic introductions have risen exponentially as commerce and travel have increased. Recent concern about and study of invasions has captured a small time period in a continual process. Responses to this problem need to consider the on-going nature of this process. The existing invaders need to be addressed through control measures. However, some are so fully adapted to their new ecosystems and so resistant to control measures, that they appear to be permanent components of the biological community in the Galveston Bay ecosystem, e.g. nutria, starlings, fire ants, and Chinese tallow.

Management resources will always be limited and should be distributed according to some benefit-cost evaluation. One assumption to a benefit-cost evaluation of current versus potential invasions is that both control and prevention should be parts of a viable strategy for minimizing the damage of invasive species. Prevention is likely to consist of development of and education regarding best practices associated with those forms of commerce most likely to provide avenues for invasion. Prevention is also likely to be less expensive and yield greater ecological benefits than controlling species that have already become well established.

The risk assessment and management assessment performed in this study have biases that favor high ranks for existing invaders. This does not detract from the need to balance investment in control and prevention. The shortage of potential invaders from the list of top candidates for management action does not reduce our capability to obtain such balance. It is very likely that every invasive species currently established in the Lower Galveston Bay watershed will require an individual control plan because each of these species will have different distributions and responses to control measures.

Potential invaders will be managed by prevention measures that will be applied to modes of transport. Ballast water treatment or exchange is designed to interdict all potential inhabitants of ballast water, not individual species. Thus identifying only a few high-risk potential invaders is sufficient to justify implementation of best practices for preventing introduction through a certain transport mechanism.

5. Recommendations

Invasive species represent a considerable risk to the human uses of Galveston Bay and the human and natural communities that coexist in the watershed. Control of some of these species is already a financial burden on resource management agencies and individuals. This is a problem that must be addressed by public policy and individual actions.

The following recommendations suggest actions and changes that could be taken to better address the problem. They are intended to serve as guidelines for improving the response to the problem of invasive species in the Galveston Bay watershed. Some organizations and people have already implemented one or more of the following recommendations. The list of recommendations is not meant to imply lack of action on all of the topics covered, but to outline a comprehensive approach to the problem.

The authors have considered the results of the risk assessment and research/management evaluation and the comments made during the process by the participating experts. The recommendations are consistent with opinions held by multiple members of the participants; but they should be attributed only to the authors because they were not developed in the workshops and have not been reviewed by the participants.

5.1. Resources

There are insufficient resources available to reverse the spread of damaging invasive species or to effectively reduce new introductions. In the case of management of invaders amenable to control, the funds needed for pesticides, herbicides or mechanical devices and personnel to hold the line on further spread of the high-risk invasive species far exceeds the dedicated resources. This became obvious in our discussions of active control and prevention programs. More financial and personnel resources should be allocated to the problem of control and prevention of exotic invasive species.

5.2. Monitoring

Based on available evidence, prevention or early eradication is less expensive than control of established invaders. This approach has been justified for agricultural pests and seems to hold for invaders of natural habitats. Too little attention is paid to monitoring ecosystems for introduction of exotic species and facilitation of early eradication. Monitoring programs should be funded and implemented that will provide early detection of exotic invasive species.

Multiple agencies have responsibilities for control and prevention of invasions by exotic species depending on the habitat, e.g. Texas Department of Agriculture for crop and grazing land, Texas Parks and Wildlife Department (TPWD) for rivers, Texas Forest Service for forests, health departments for pathogens in the urban ecosystem, etc. Those state and federal agencies that own land are responsible for invasives on their property, e.g. the U.S. Fish and Wildlife Service for National Wildlife Refuges, National Park Service for national parks, TPWD for state parks and wildlife management areas, etc.

Gaps exist in the current efforts to manage problems associated with invasions. Many of the gaps are due to focus by a management organization on a subset of organisms, e.g. fish and Crustacea, but not worms; or plants, but not fungi. Organizations monitor the groups of organisms that are relevant to their mission. Some of the gaps are due to lack of jurisdiction for private lands. It is difficult to manage the problem when much of the land area is not subject to monitoring or control actions. There is some coordination among the agencies and others to address a critical problem, e.g. the Invasive Species Working Group of GBEP. But no organization in the Galveston Bay watershed has authority to coordinate among responsible parties for the management of invasive species. A formal coordination mechanism should be established among agencies with authority for invasive species management and gaps in responsibility addressed.

5.3. Prevention

The transport of potential invaders is often in conjunction with commercial activity, e.g. ballast water transport with shipping or invasive plants from horticulture. Political action is necessary to regulate commercial activities, but the potential damage to natural resources can provide a benefit-cost analysis to justify such action. Prevention programs involving regulation of commercial activities to minimize importation and spread of invasives should be promulgated.

Regulations have been or are being developed to deal with some portion of the risk of invasions from transport in the pet trade, horticulture, agriculture, aquaculture, and the live seafood market. The fundamental approach in most cases is based on a restricted list of species that are precluded or require special permits. Lists of nuisance species should be updated by collaborative processes among all management agencies with responsibility for invasive species. Inspection programs should be maintained and strengthened.

5.4. Control

Organizations engaged in control programs for invasive species should collaborate to increase spatial and temporal coordination and increase opportunities for eradication of high risk invaders. Planning to achieve clear priorities and recognize synergies among correlated control efforts will improve cost effectiveness of eradication programs. Examples of such coordination have occurred.

Control methods should be chosen based on efforts to minimize collateral damage on native flora and fauna. Many of the cost effective control methods use lethal chemicals. These can be justified by the benefit-cost analysis of the impacts from the invasion. However, impacts on native biodiversity from control efforts should be a major consideration in the benefit-cost evaluations. Many current control efforts take this into consideration.

Programs to increase participation of private landowners in control of invasive species should be promoted. Private land owners are responsible for 97 percent of the wildlife habitat in Texas (TPWD, 2003). Therefore, involvement of private land owners is essential to efforts to control and eradicate terrestrial and freshwater invaders. There can be no participation by private landowners if they have not been informed about invasives that could be on their property. Education about invasives must be improved and must target private landowners. Knowledge alone may be insufficient to achieve action from landowners. For that reason, financial incentives for control of invasives by private landowners should be developed for species for which the benefits of eradication are high.

5.5. Research and Education

Prevention of new invasions should be an efficient method to lower the cost to society of invasive species. It will be difficult to design an efficient prevention program with the information currently available. We found little information on the risk associated with different mechanisms of transporting potential invaders. Management tends to be accomplished by monitoring for the presence of species on forbidden lists. So there is no quantitative assessment of how many potential invaders are present in ballast water of ships coming from South America, in live seafood shipments from Asia, in shipments to pet stores from Europe, etc. Quantitative studies of the frequency of potential invaders associated with various methods of transport should be undertaken and used to prioritize prevention efforts.

Research should be conducted on cost effective, minimal impact methods for the control of high-risk invaders. Control methods for some invasive species are unknown or possible controls are untested. Control methods should not be applied in large eradication efforts without good knowledge of their effects. Research on control methods should be pursued with a least toxicity-least cost goal.

Some groups of organisms get very little attention by resource management agencies, e.g. fungi and plankton. It is impossible to determine the status of a newly recorded species in a location if there is no baseline of biodiversity. In the Galveston Bay watershed, there are reasonable baselines for terrestrial plants and vertebrates, as well as freshwater and estuarine vertebrates. Benchmark studies of the biodiversity in poorly documented groups of organisms in the three habitats should be encouraged.

There are too many potential avenues for transport of invasive species to develop regulatory approaches to all of the possibilities. Efforts should be directed toward educating the public about the impacts of invasives and potential pathways for introductions. Educational materials designed to reduce introductions by members of the public should be developed and distributed to targeted audiences.

Often the public participates in introduction of invasives after purchasing the species from a business near their home or business. This connection between certain forms of commerce and introductions of exotic species needs to be addressed with educational programs also. Educational materials on invasives targeted at horticulturists, pet and aquarium storeowners, farm and ranch supply, live seafood marketers, developers, etc. should be improved and gain wider dissemination.

6. Conclusion

The ecological health of the Lower Galveston Bay watershed has already been degraded by multiple invasions of exotic species. There are other invasive species that have not yet arrived in the watershed, but represent significant future risks. The list of existing and potential invasive species for this watershed is so extensive that the process we designed could not accommodate all of them. Yet the list is certainly incomplete because there are no representatives of some major taxonomic groups. This suggests that our monitoring programs have gaps in coverage of some types of organisms. There are also species that have been classified as invaders, but are unstudied and cannot be evaluated.

Comparative risk assessment by experts worked well to prioritize risks, but could be refined to reduce overlap among criteria and the bias in favor of existing invaders. The process yielded rankings of invasive species that are logical and can be used to support management decisions. The rankings described here document the greater extent of the problem in terrestrial and freshwater habitats versus the estuarine habitat.

Control techniques exist for many species and there is optimism that invaded habitats will recover after eradication. However, control technologies are more easily targeted in terrestrial habitats and are limited due to lack of resources for all habitats. Thus freshwater and estuarine habitats are more likely to be irreversibly invaded than terrestrial habitats. Prevention is likely to be only partially effective in lowering the invasion rate, but could be very cost effective for organisms spread by specific human activities, such as the pet trade.

Stemming the tide of invasions by exotic species will require much more research and education directed toward the problem. From detecting invaders to designing control programs, we suffer from significant information gaps. Control and prevention will also require the allocation of resources and changes in human activities.

Currently the number of examples of serious damage done by invaders significantly outnumbers the examples of successful eradication. Changing this dynamic is possible through the collective and individual actions of citizens who can obtain information, provide resources and change their behavior as it relates to the spread of exotic species. Implementation of the recommendations contained in this report will not eliminate all existing invasive species or stop all future invasions, but it would provide significantly better protection for the resources and services provided by the Galveston Bay watershed.

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8. Appendices

Appendices are included as separate attachments to this report.

Appendix A – List of Original 296 Invasive Species Identified by the Galveston Bay Risk Assessment Project

Appendix B – Annotated Bibliography

Appendix C – Sample Survey Form

Appendix D – Risk Assessment Work Groups

Appendix E – Collection of Species Summaries

Appendix F – Overall Ecological Risk Rankings

Appendix G – Species Rankings According to Individual Ecological Risk Criteria

Appendix H – List of Species Targeted for Prevention and Control

Appendix I – List of Species not Ranked by the Galveston Bay Risk Assessment