Valuing Nature in Texas

HARC

The Role of Freshwater Inflows in Sustaining Estuarine Ecosystem Health in the San Antonio Bay Region

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1. Introduction

Estuaries are vital aquatic habitats for supporting marine life, and they confer a multitude of benefits to humans in numerous ways. These benefits include the provision of natural resources used for a variety of market activities, recreational opportunities, transportation and aesthetics, as well as ecological functions such as storing and cycling nutrients, absorbing and detoxifying pollutants, maintaining the hydrological cycle, and moderating the local climate. The wide array of beneficial processes, functions and resources provided by the ecosystem are referred to collectively as "ecosystem services." From this perspective, an estuary can be viewed as a valuable natural asset, or natural capital, from which these multiple goods and services flow.[1]

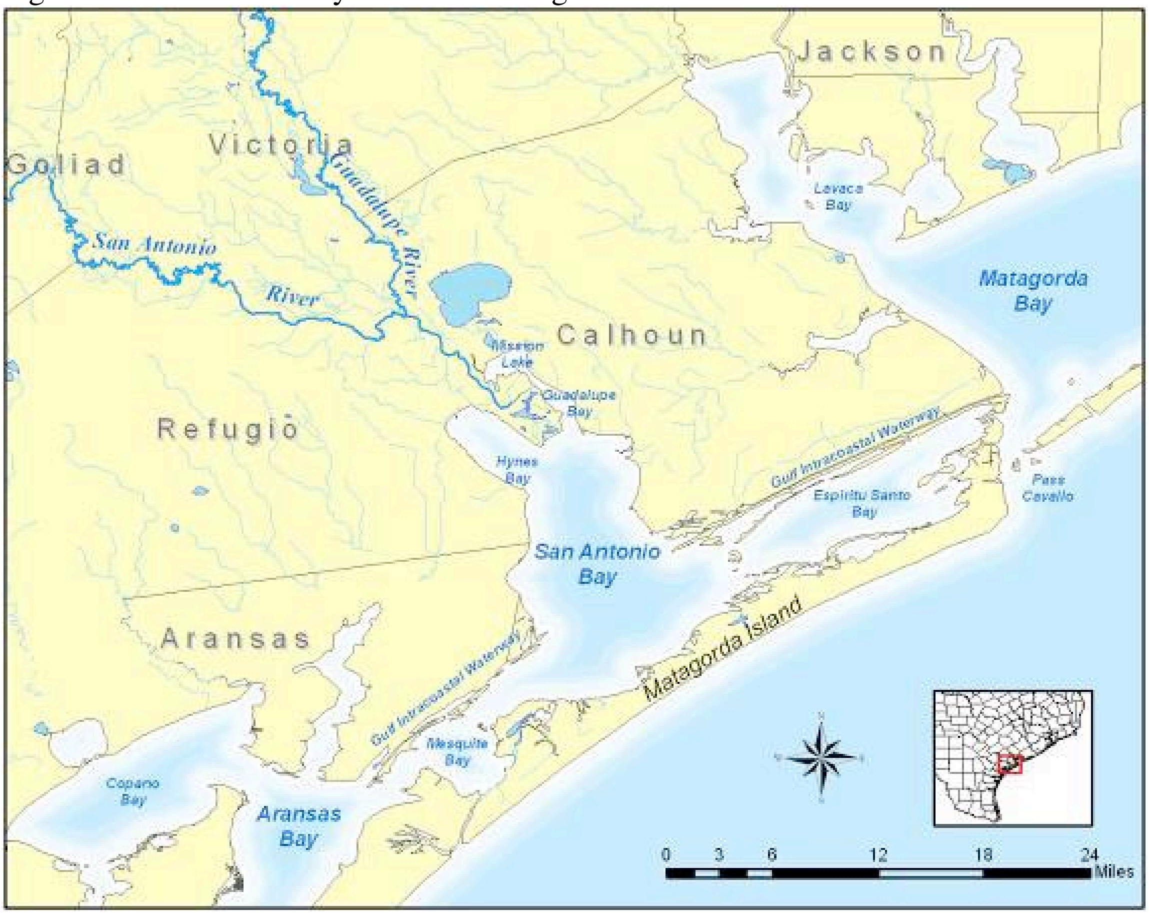
The quantity, quality and temporal variance of freshwater inflows are essential to the living and non-living components of bays and estuaries. Freshwater inflows to sustain ecosystem functions affect estuaries at all basic physical, chemical, and biological levels of interaction. The functional role of freshwater in the ecology of estuarine environments has been scientifically reviewed and is relatively well understood. This role is summarized in section 3, after a brief overview of the geographical context of the San Antonio Bay Region in the next section. Section 4 follows with discussion of the impacts of reduced freshwater inflow to the San Antonio Bay. Section 5 concludes with some general observations.

2. Geographical Context

The San Antonio Bay Region, formed where the Guadalupe River meets the Guadalupe Estuary, teems with life. The San Antonio Bay and its related intracoastal system cover an area of approximately 100 square miles and include Mission Lake, Guadalupe Bay, Hynes Bay, Espiritu Santo Bay and Mesquite Bay. Matagorda Island serves as a barrier separating the San Antonio Bay from the Gulf of Mexico. The bay averages less than six feet in depth.[2] Espiritu Santo Bay and Matagorda Bay are located just to the north of San Antonio Bay while Mesquite Bay and Aransas Bay are located to the south.

[1] Costanza et al. (1997) observed that ecosystem services consist of materials, energy, and information from natural capital stocks, which combine with manufactured and human capital services to produce human welfare.
[2] East, J. W. November 2001. Discharge Between San Antonio Bay and Aransas Bay, Southern Gulf Coast, Texas, May–September 1999. U.S. Geological Survey in cooperation with Texas Water Development Board, Fact Sheet 082-01

Figure 1. San Antonio Bay and surrounding area.



The main connection to the Gulf of Mexico for San Antonio Bay is through Pass Cavallo at the southern end of Matagorda Bay. San Antonio Bay is hydraulically connected by the Gulf Intracoastal Waterway (GIWW), a dredged channel that runs along the entire Gulf Coast. The GIWW is a maintained navigation channel that is more than 300 feet wide and about 15 feet deep.

The majority of the freshwater inflows to San Antonio Bay come from the Guadalupe and San Antonio Rivers. Historically, the Guadalupe and San Antonio Rivers have supplied over 79.6% of the total freshwater inflows into this estuary.[3] The gauged areas of the Guadalupe River alone accounted for 56.9% of the total freshwater inflows into the estuary.[4] The Guadalupe River originates in the southern edge of the Edwards Plateau. The Upper

[3] Longley, William L. ed. 1994. *Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs*. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX.
[4] Ibid.

Guadalupe is shallow, with swift flows, receiving inputs from many minor tributaries that flow intermittently following rainfall events. The San Antonio River originates within the San Antonio city limits, on the northern edge of the South Texas Brushlands, and flows in a southeasterly direction. The San Antonio River joins the Guadalupe River approximately 16 km (9.94 miles) before entering San Antonio Bay on the Texas coast.

The Guadalupe Estuary has a definite salinity gradient with relatively large areas having different salinities at intermediate inflow volumes. It has fresher areas near the Guadalupe River mouth (Mission Lake Guadalupe Bay, Hynes Bay), and high salinity areas in Espiritu Santo Bay near Pass Cavallo, one of the major bay-Gulf of Mexico passes.

3. The Role of Freshwater Inflows to Sustain Estuarine Ecosystems

The following list of the roles of freshwater inflows in sustaining estuarine ecosystems is taken from Longley (1994) and is accompanied by a brief explanation of each of these effects. These functions of freshwater inflow apply to estuaries in general and may not apply specifically to the San Antonio Bay.

3.1. Functional role of freshwater inflow

3.1.1. Dilution of Seawater

A primary role of freshwater inflows is the mixing with seawater to create brackish conditions typical of most bays and estuaries. Many commercially and recreationally important species rely on the lower salinity conditions of estuaries for at least some portion of their life cycle.

3.1.2. Dilution of contaminants

Freshwater inflow into bays and estuaries carries with it contaminants from land surfaces within the watershed. The contaminants are transported into bays and estuaries where they are diluted in the greater volume of water. The dilution effect is limited by assimilative capacity of bays and estuaries and their various habitats.

3.1.3. Creation and maintenance of nursery habitats

Freshwater inflows are vital to the creation and maintenance of estuarine habitats which provide food and protection to many organisms including finfish, crustaceans, birds, reptiles, and mammals.

3.1.4. Reduction of metabolic stresses in estuarine dependent organisms

Salinity concentrations in bays and estuaries are naturally variable. To deal with the variability, all estuarine organisms have a range of salinity concentrations that they can tolerate based on their ability to regulate concentrations of internal body salts relative to environmental salinity. Drastic changes in salinity regimes can impair an organism's ability to maintain osmotic balance triggering metabolic stresses. Metabolic stresses can lead to increased incidence of disease, parasitism and can have a negative effect on the ability of organisms to forage and reproduce.

3.1.5. Transportation medium for beneficial sediments and nutrients; cycling, and the removal of metabolic waste

Freshwater flows provide a medium for the transport of suspended particulate matter including sediment, detritus (decaying organic material) and organisms such as phytoplankton. Additionally, freshwater inflows transport nutrients (e.g. nitrogen and phosphorus) from watershed point sources (e.g. wastewater treatment) and non-point sources (i.e. runoff) to bays and estuaries.

3.1.6. Modification of concentration dependent chemical reactions of particles in the saltwater environment

Various compounds adhere to the surface of suspended particles and interact with other chemical constituents in the water column. Freshwater inflows are not only a source of suspended particles, but also influence salinity levels which have a direct effect on the rate of chemical reactions, ion-exchange, coagulation and precipitation of particles.

3.1.7. Creation of a resource partitioning mechanism among estuarine plants and animals

The combined effects of inflow on salinity, temperature, and turbidity influence the distribution of ecological producers and consumers in the estuary. When foraging, species must very often share one resource such as a specific wetland area or mudflat. Resource partitioning ensures that multiple species (crustaceans, finfish, birds) are able to utilize the same resource, but each in a different way. Freshwater inflows ensure diversity among habitat types as well as the consuming organisms dependent upon them.

3.1.8. Distribution and vertical movement of organisms in the water column related to stimulation of positive phototaxic or negative geotaxic behavioral response

Positive phototaxis describes an organism's upward movement in the water column toward a light source; negative geotaxis describes an organism's upward movement in the water column against gravity. Changes in salinity, triggered by changes in freshwater inflows, have been shown to have an effect on the phototaxic and geotaxic behavior of estuarine organisms, especially larval finfish and crustaceans.

3.1.9. Creation of a cutting and filling mechanism that affects erosion and deposition in the bays and estuaries

Freshwater inflows play an important role in the physical characteristics of bays and estuaries. They influence circulation patterns and can increase the erosion of bay shorelines and habitat. Freshwater inflows also provide a transport mechanism for sediments that can accrete on bay shorelines or deposit in the open bay.

3.1.10. Creation of a salt wedge and mixing zone in concert with tidal action

Estuaries are areas where freshwater from land and saltwater from the ocean mix. Less dense freshwater pushes against and rises above the more dense saltwater forming a salt wedge. The movement of the salt wedge between the freshwater and saltwater sources depends upon the volume of freshwater flowing into the estuary and the tidal forces moving saltwater into and out of the estuary.

3.1.11. Transportation of allochthonous nutritive materials into bays and estuaries as a function of topography, rainfall and drainage area

Freshwater inflows bring external organic and inorganic materials into the bays and estuaries, providing desirable nutrients to the ecosystem.

3.1.12. Migration and orientation of migratory organisms like the penaeid shrimps and many marine fishes

The movement of organisms into and out of an estuary is dependent on seasonal physical cues including tides, temperature, photoperiod, and salinity. Additionally, some organisms, such as shrimp are dependent on currents and tides for their large scale movement within the estuary.

3.1.13. Stimulation of some plants and animals that may be considered less desirable to humans such as "red tide" and others

In addition to the estuarine organisms deemed as beneficial or benign by humans, noxious organisms such as the naturally occurring red tide algae and pathogenic bacteria such as Vibrio and fecal coliforms are present. Populations of these undesirable organisms are limited by certain physical conditions including temperature and salinity. In the case of fecal coliform bacteria, freshwater inflow acts as a mechanism by which the bacteria is transported from the watershed to the bay. In the case of red tide and Vibrio vulnificus, adequate freshwater inflows can inhibit their growth, preventing adverse impacts to finfish, shellfish, and humans.

3.2. Variable freshwater inflows

3.2.1. Dynamic nature of estuaries

Dynamic and seasonal fluctuations are realistic and necessary for Texas bays and estuaries. Additionally, many multi-year patterns exist as well. The seasonal timing of freshwater inflow is particularly important because adequate inflows during critical periods of reproduction and growth are better for ecosystem health and organism populations than constant inflow throughout the year. However, extended low inflow conditions can lead to degraded estuarine environments, loss of important nursery areas for economically valuable fish and shellfish resources, and a reduction in the ability of the ecosystem to produce its wide array of goods and services.[5]

3.2.2. Large scale weather patterns on inflow

Dramatic fluctuations exist due to long-term weather patterns that produce droughts and floods. The 22-year Hale double-sunspot cycle and the 18.6-year lunar nodal cycle seem related to periods of drought. However, research has demonstrated that over the past 300 years the recurrence interval of approximately 20 years for major droughts is not accurate enough for forecasting purposes.[6] Observed climatic cycles have demonstrated tendencies for clusters of wet or dry years to occur, and that several individual years in a cluster will contain a particular extreme condition. For example, the hot dry years during the 1980's after a number of several wet years in the 1970's was a normal cycle for a semi-arid region such as Texas.[7]

3.2.3. Human interference

Due to a rapidly growing population in the Gulf States, particularly along the coast and in cities along major rivers that flow into the Gulf has created problems that threaten the quantity and quality of the Gulf's freshwater supply. Innumerable rivers and streams carry industrial and community waste and street runoff to the Gulf from many cities and communities, causing pollution of the bays and estuaries. This pollution, combined with accidental coastal chemical discharges and oil spills, sometimes dumps more wastes into bays and estuaries than the systems can treat effectively, affecting the health and productivity of the coastal ecosystem.

Demands of a growing population have placed unprecedented pressure on bays and estuaries, competing with the ecosystem for many uses. Diversion of water for community use, construction of dams, channelization, and wastewater discharges all affect freshwater inflows. While benefiting communities, many of these activities have also generated problems. Damming rivers and streams to form reservoirs for flood control, community use and for recreation have permanently changed water flow patterns and reduced freshwater inflows and necessary nutrients. Channelization to provide flood protection built in natural flood plains and former wetlands have caused problems as well.

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[5] Longley, W.L. ed. 1994. *Freshwater inflows to Texas bays and estuaries: Ecological relationships and methods for determination of needs*. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX, 2.
[6] Meko, 1985 in Longley, W.L. ed. 1994. *Freshwater inflows to Texas bays and estuaries: Ecological Relationships and Methods for Determination of Needs*. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX.
[7] Longley, W.L. ed. 1994. *Freshwater inflows to Texas bays and estuaries: Ecological relationships and Methods for Determination of Needs*. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX, 2.

3.3. Effects of reduced freshwater inflows

3.3.1. Increased salinity of bay, estuary, and nearshore maritime waters

An increased salinity of bay, estuarine, and near shore maritime waters can disrupt the ecosystem, altering the composition and distribution of plant and animal populations. Increased salinities can also facilitate the growth of pathogenic bacteria such as red tide and Vibrio vulnificus.

3.3.2. Reduced mixing due to salinity differences and stratification of the water column

Reduced inflows may increase salinity stratification and lead to a decrease in mixing, causing a change in plant and animal species composition and decreased diversity.

3.3.3. Penetration of salt-wedge farther upstream allowing greater intrusion of marine predators, parasites, and diseases

With decreased freshwater inflow, the salt-water wedge will push farther into the estuary. The resultant influx of marine predators, parasites, and diseases will negatively impact estuarine organisms and habitats that depend on a lower salinity regime.

3.3.4. Saltwater intrusion into coastal groundwater and surface water resources used by man

With decreased freshwater inflow, the salt-water wedge will push farther into the estuary, infiltrating groundwater and surface water supplies used by humans for irrigation, drinking water, and industry.

3.3.5. Diminished supply of essential nutrients to the estuary from inland or local terrestrial origins

A diminished supply of nutrients from the watershed to the estuary can become a limiting factor in the ecosystem's overall productivity.

3.3.6. Increased frequency of bottom sediments becoming anaerobic, liberation of toxic heavy metals into the water column that had been sequestered in the benthic substrates, and sulfur cycle domination

Decreased freshwater inflows can increase the occurrence of sediments with little or no oxygen. When oxygen is lacking in the sediments, microorganisms switch metabolic processes to utilize sulfur. Thus, the concentration of sulfur compounds increases in the anoxic sediments typically in the form of hydrogen sulfide. Heavy metals bounds to sediments under normal conditions are released into the water column under anoxic conditions becoming biologically available to the food web.

3.3.7. Reduced inputs of particulates and soluble organic matter with flocculation and deposition of the particles locally, rather than being more widely dispersed throughout the estuarine ecosystem

Freshwater inflows transport suspended particulate and organic matter from the watershed to the estuary. When freshwater inflows decrease, particles flocculate (or bind together) and settle out of the water column closer to the source rather than throughout the estuary making the particulates less available to estuarine organisms.

3.3.8. Loss of economically important seafood harvests from coastal fisheries' species for a variety of reasons related to high salinity conditions, reduced food supply, and loss of nursery habitats for the young

Commercial fisheries and recreational fisheries are extremely valuable industries in the State of Texas. Most commercially and recreationally important species rely upon bays and estuaries for at least some portion of their life cycle. With decreased freshwater inflows, salinity in the estuary increases having a negative impact on the habitats that provide food and shelter to the estuarine food chain. The loss of habitat, food supply, and nursery areas would have a detrimental effect on commercial and recreational fisheries stocks

3.3.9. Loss of characteristic dominance of euryhaline species in the bays and estuaries to stenohaline species as natural selection occurs for species more fully adapted to marine conditions in general

As freshwater inflow decreases so does the variability of salinity concentrations. As salinity rises over the long term, euryhaline species (able to tolerate a wide range of salinities) inhabiting bay waters are replaced by higher salinity, stenohaline species able to withstand only a narrow range of salinities. A decline in species diversity could result..

3.3.10. Increased incident of human diseases caused by bacteria in seafood

Estuarine species, particularly filter-feeding oysters, consumed by humans are subject to bacteria present in the water column. Of special concern are the bacteria of the genus, Vibrio. Native and exotic species of Vibrio are present in many bays and estuaries in Texas, but populations of Vibrio increase under conditions of warm water temperature and high salinities. Freshwater inflows are vital to control population explosions of these harmful bacteria that can cause illness in humans when ingested.

3.3.11. Deterioration of salt marshes, mangrove stands, and sea grass beds if under elevated salinities

Salt marshes, mangrove stands, and sea grass beds provide numerous ecosystem functions, such as providing nursery areas and preventing erosion. Elevated salinities can cause deterioration and degradation of these habitats and the ecosystem services that they provide.

3.3.12. Loss of sand/silt renourishment of banks and shoals resulting in erosion

Freshwater inflows transport sediment loads to bays and estuaries where the particles drop out of suspension to replenish bank and shoal sediments lost to erosion. Reduced freshwater inflows would lessen the supply of renourishment material resulting in a loss of some banks and shoals over time as erosion processes continue.

3.3.13. Alteration of littoral drift and nearshore circulation patterns

Freshwater inflows and transported sediment not only impact the circulation patterns and sediment budget within bays and estuaries but also exit the bay system and impact the beach shoreline. A reduction of freshwater inflows could reduce the sediment load deposited along the beach shoreline, decreasing the accretion of sediments along nearby, down-current bars and barrier islands.

3.3.14. Aggravation of all negative effects during drought periods

Variations in salinity are necessary to maintain the health and productivity of bays and estuaries. Strong periods of freshwater inflow are just as important as periods of natural drought. While ecosystems are stressed naturally due to droughts, reduced inflows due to human diversions of freshwater can artificially increase the duration and frequency of drought conditions with deleterious effects on the estuarine ecosystem.

4. Observed and Potential Effects of reduced freshwater inflows in the San Antonio Bay Ecosystem

San Antonio Bay is especially vulnerable to changes in timing of flows since it lacks a direct connection to the Gulf. It may become mostly fresh following a flooding event or hyper-saline during drought conditions.[8] From 1941 to 1987, the Bay received an average of 2.3 million acre-feet of inflow annually. The overall rates of freshwater inflows increased during this period, "which can be attributed to increased urbanization in the watershed, increased groundwater pumping and return flows and increased precipitation in the latter period."[9]

General relationships between Gulf estuary productivity and freshwater inflows have been identified. Deegan et al. (1986) found that freshwater input was highly correlated

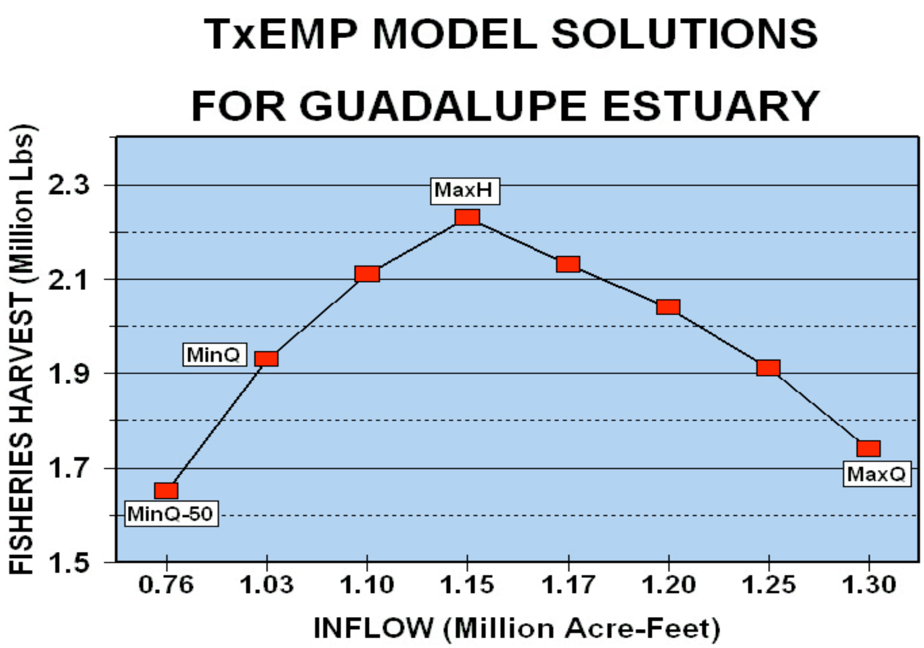
[8] Texas Parks and Wildlife Department. 2004. Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas. http://www.tpwd.state.tx.us/texaswater/coastal/freshwater/guadalupe/guadalupe.phtml. Accessed July 5, 2005.

[9] Longley, W.L. (ed.). 1994. Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, Texas. 386p.

(r=.98) with fishery harvest.[10] In (Longley, 1994), the Guadalupe Estuary is examined with respect to inflow levels and populations of seven commercially important fisheries species (red drum, black drum, spotted sea trout, blue crab, bay oyster, and white and brown shrimp). Additionally, inter-estuary comparisons of spotted sea trout, blue crab and white shrimp harvests are examined as well. In general, all species harvests examined tended to have a strong linear correlation with increased freshwater inflows.[11]

However, it is important to note that increased freshwater inflows also indicate increased *variability* in freshwater inflows.[12] A graphical depiction of the relationship between freshwater inflows and fishery productivity is shown in Figure 2. Based on data from Guadalupe estuary, the figure indicates that a continuous increase in freshwater inflows will eventually lead to a decline in fishery productivity.

Figure 2: Fisheries Harvest vs. Freshwater Inflow in the Guadalupe Estuary [13]



Source: Texas Water Development Board (2004)

Evidence from other literature and results from the economically important species studied suggests that populations of white shrimp, oysters, and blue crabs would most likely

[10] Deegan et al. 1986, in Livingston, Robert J. "Historical relationships between research and resource management in the Apalachicola river estuary," *Ecological Applications*, 1(4) 1991, 362.
[11] Longley, W.L. ed. 1994.
[12] Personal communication with Lisa Gonzalez 5 April 2004.
[13] Texas Water Development Board. March 2004. Guadalupe estuary study results. http://hyper20.twdb.state.tx.us/data/bays_estuaries/TxEmp/guadalupechart2.jpg Accessed 8 June 2006.

decline with decreased freshwater inflows. For brown shrimp, high salinity or low salinity concentrations would adversely affect catch rates. It has proven much more difficult to measure catches of finfish due to a variety of complex indirect effects and their long lifespan. However, there is some evidence that juvenile Gulf menhaden and southern flounder are negatively affected by increased salinity.[14]

4.1. Effects of Availability of Blue Crabs on the Whooping Crane Population

The whooping crane is one of the most famous birds occupying a place on the endangered species list. They breed in wetlands of Wood Buffalo National Park in the Northwest Territories of Canada and winter on the coastal wetlands of the San Antonio Bay Region. Hunting pressures and habitat loss reduced the population to fewer than 15 individuals in 1941. Since then, protection under the federal Endangered Species Act (including habitat protection provided by the Act) has resulted in a gradual increase in numbers. During the winter of 2004-05, 217 birds wintered in Aransas National Wildlife Refuge and other protected areas that surround the San Antonio Bay.[15]

While wintering in the San Antonio Bay region, the whooping crane's main source of energy comes in the form of blue crabs.[16] In a year of high crab abundance, whooping cranes can consume 7-8 crabs per hour (80 crabs per day), totaling 80-90% of their diet. In contrast, during years of low blue crab abundance, cranes consume an average of only three crabs per hour (about 35 crabs per day).[17] A 1996 study of the principal food items of whooping cranes showed that blue crabs were the highest in protein and overall nutritional value for the cranes.[18] Whooping cranes will switch to other foods when crabs are hard to come by, but because of the poor nutritive value of these alternate foods, the cranes barely, and in some cases do not, meet their daily energy requirements.[19]

When an organism consumes more energy than it can utilize in a day, it stores the energy in the form of fat. The stored energy is important for the cranes' survival since it provides the energy necessary to complete the long migration to the breeding grounds. In the eight-year period from 1993-2001, the Fish and Wildlife Service conducted surveys that roughly estimated the number of blue crabs available to whooping cranes. Two winters (1993-94 and 2000-01) had lower than normal numbers of crabs. During those winters, seven and six whooping cranes died respectively. In the six other winters with normal numbers of

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[14] Longley, ed. 1994.
[15] Stehn, T. 2005. Whooping crane recovery activities. http://www.whoopingcrane.com/wccatoday.htm. Accessed August 18, 2005.
[16] Guillory, V. and M. Elliot. 2001. A review of blue crab predators. proceedings of the blue crab mortality symposium 69-83. Gulf States Marine Fisheries Commission Publication Number 90.
[17] Chavez-Ramirez, F. 1996. Food availability, foraging ecology and energetics of wintering whooping cranes in Texas coast. Unpublished PhD Dissertation. TAMU, College Station, Texas. 105pp.
[18] Nelson, J. T., R.D. Slack, and G.F. Gee. Nutritional value of winter foods for whooping cranes. 1996. *Wilson Bulletin* 108(4): 728-739.
[19] Chavez-Ramirez, F. 1996. Food availability, foraging ecology and energetics of wintering whooping cranes in Texas coast. Unpublished PhD dissertation. TAMU, College Station, TX. 105pp.

crabs, 0-1 crane died.[20] These observations appear to confirm the inverse correlation between blue crab abundance and whooping crane mortality.

In addition to increased mortality of adult cranes, there seems to be a correlation between good crab years and good nesting and productivity the following spring.[21] Following the poor blue crab winter of 1993-94, 37 % of the known adult pairs (17 out of 46) failed to nest following their return to Canada. This was unusual since normally just about all pairs attempt to nest annually.[22] These observations suggest that sufficient inflows are required to produce the necessary food that will help ensure the survival of the species.

Freshwater inflows have an even more direct connection to whooping crane survival than through blue crabs. Whooping cranes can drink water directly from the bay when the salinity is less than 23 parts per thousand (the salinity of seawater is 35 parts per thousand). When marsh and bay salinities exceed 23 parts per thousand (ppt), the cranes must fly to freshwater water sources in order to drink. These flights use up energy, reduce time available for foraging or resting, and could potentially make the cranes more vulnerable to predation in the uplands.[23]

As stated previously, there tends to be a strong linear correlation between the blue crab population and increased freshwater inflows. [24] In the Guadalupe Estuary, blue crabs are most abundant in salinities that average between 10-25 ppt.[25] TPWD data suggests that water inflows greater than 1.3 million acre-feet annually results in low enough salinities in the estuary to produce high numbers of blue crabs. [26] In San Antonio Bay, the years with the highest harvests all had inflows greater than 3 million acre-feet.[27] Therefore, according to Longley, the salinity level should remain between 10 and 20% for approximately 60 to 80% of the time for maximum production of the blue crab species as well as the white shrimp, gulf menhaden and brown shrimp.

It is especially important to continue to study this issue as the human population in south Texas is expected to double over the next 50 years causing great shifts in the water use

[20] Stehn, T. 2001. Relationship between inflows, crabs, salinities and whooping cranes. Journey North: http://www.learner.org/jnorth/tm/crane/Stehn_CrabDocument.html Accessed June 24, 2005.
[21] Chavez-Ramirez, F. 2003. Whooping cranes, crabs and freshwater inflows: A delicate chain. *The ICF (International Crane Foundation) Bugle* 2(4):2-3.
[22] Stehn, T. 2005. Whooping crane recovery activities. http://www.whoopingcrane.com/wccatoday.htm. Accessed August 18, 2005.
[23] Chavez-Ramirez, Felipe. 1996. Food availability, foraging ecology and energetics of wintering whooping cranes in Texas coast. Unpublished PhD Dissertation. TAMU, College Station, Texas. 105pp.
[24] Longley, W.L. ed. 1994.
[25] San Antiono/Guadalupe Estuarine System (SAGES). 2005. Project description. http://sages.tamu.edu/proj_desc.cfm. Accessed 30 July 2006.
[26] Longley, W.L. (ed.). 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, Texas. 386 p.
[27] Stehn, T. 2001. "Relationship between inflows, crabs, salinities, and whooping cranes." Journey North. http://www.learner.org/jnorth/tm/crane/Stehn_CrabDocument.html. Accessed August 18, 2005.

in this region. The Texas Water Development Board projects an 8% reduction in blue crab population in the next 40 years due to reduced inflows, as humans take more water from the Guadalupe River and hence the San Antonio Bay.[28] A study funded by the Guadalupe Blanco Water Development Board, the San Antonio River Authority and other water groups will build on and expand this work of the TWDB and TPWD, with specific application to the fresh water inflow needs of the San Antonio Bay ecosystem.

> "The goal is to provide a new, additional source of water to meet future needs in the South Texas region, while helping to protect spring flows at the Comal and San Marcos Springs and preserve inflows to the San Antonio-Guadalupe bays and estuary system."[29]

Specifically, Texas A&M University is conducting a multi-faceted research project involving extensive collection of field data with the ultimate objective of linking freshwater inflows and marsh community dynamics in San Antonio Bay to whooping cranes.[30] In addition, the Center for Research in Water Resources at the University of Texas at Austin is engaged in a research effort focusing upon the influence of freshwater inflows on the ecological health of San Antonio Bay.[31]

5. Conclusions

Estuarine ecosystems provide myriad ecosystem functions, including many goods and services used by humans. These estuarine ecosystems are dependent upon freshwater inflows in order to maintain their ability to function properly. Among many purposes, freshwater inflows affect the salinity concentration, move nutrients and pollutants through the ecosystem, and seasonally fluctuate accommodating the needs of the many species that use estuaries for at least one part of their life cycle.

In general, the roles of freshwater are relatively well understood, as well as the effects of reduced freshwater inflow. However, studies that link fish populations to freshwater inflow are quick to point out that there are many complexities in the system due to relationships between species, nutrients, and other input factors into the ecosystem. More important than a large quantity of inflows, however, is the large seasonal fluctuation of inflows. A myriad of organisms depend on the ecosystem for different periods of their life cycles. Seasonal fluctuations, droughts, and floods are necessary in order to maximize the productivity of estuaries for fishery purposes. While increased inflows generally have a

[28] Chavez-Ramirez, Felipe. 2003. "Whooping cranes, crabs and freshwater inflows: A delicate chain." *The ICF (International Crane Foundation) Bugle* 2(4):2-3.
[29] Lower Guadalupe Water Supply Project. 31 August 2004. Fact Sheet. http://www.sara-tx.org/site/Water_Resources/lgwspsept04.pdf. Accessed 30 July 2006.
[30] Lower Guadalupe Water Supply Project. June 2005. 2006 South Central Texas Water Supply Plan, Vol. 2. HDR-07755099-036 http://www.twdb.state.tx.us/RWPG/2005_1PP/Region%20L/Volume%20II/Section%204C.07.pdf. Accessed 30 July 2006.
[31] Ibid.

positive and linear correlation with increased fish populations, if inflows are consistently high, estuary productivity can decrease.

Human interference with freshwater inflow has begun to change the dynamic of San Antonio Bay Region. The ecosystem will continually have to adapt to varying amounts of freshwater inflow due to human development especially in and around the city of San Antonio. Given the mounting pressures on the environment, it is increasingly important that adequate freshwater is allocated to sustain the ecosystem. Studies have been and are currently being conducted on the San Antonio Bay Region helping people to reach a greater understanding of the role that freshwater inflows play in sustaining an estuarine ecosystem and how that ecosystem is likely to function on the Texas gulf coast.

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