INTRODUCTION

Coastal wetlands worldwide are increasingly valued for buffering the capacity of coastal storms to flood or erode uplands, filtering urban runoff, providing wildlife habitat, and supporting coastal fisheries (Beatley, Brower, and Schwab, 2002). Rapid development of coastal regions has led to the establishment of an array of local, state, and national regulatory efforts to protect these ecosystem functions. Among the national programs in the United States which support conservation of coastal wetlands is the National Estuarine Research Reserve (NERR) system.

The NERR program was created by the Coastal Zone Management Act of 1972 (National Estuarine Research Reserve System, 2004) to encourage "long-term research, water-quality monitoring, education, and coastal stewardship" (Guana Tolomato Matanzas Reserve, 2004, February 18). The reserves constituting the system are selected from areas nominated by states to represent distinct biogeographic regions. The National Oceanic and Atmospheric Administration (NOAA) provides a maximum of 70% of funding for reserve operation and state partners are responsible for providing a minimum of 30%. The federal government relies on the states to provide resource management to "ensure a stable environment for research" (National Estuarine Research Reserve System, 2005(a)). NOAA is authorized to withdraw the designation of a reserve if a stable research environment is not maintained (National Estuarine Research Reserve System, 2005(b)). This study addresses an issue which has the potential to threaten the stable research environment of the Guana Tolomato Matanzas National Estuarine Research Reserve (GTMNERR)— the issue of habitat degradation due to erosion along the margin of the Atlantic Intracoastal Waterway (AICW). Not only is such habitat degradation an issue of concern given the reserve management objectives, but it also is in conflict with the desired trend of "no net loss of wetlands" supported by local regulations (Flagler County, 2004) and federal commitments (U.S. Environmental Protection Agency, 2004).

The GTMNERR is divided into two sections, together comprising approximately 24,000 hectares (60,000 acres) in St. Johns and Flagler counties in northeastern Florida. The Guana, Tolomato, and Matanzas Rivers are the major estuarine bodies of the reserve; together they form a string of relatively narrow "bar bounded" estuaries behind the barrier islands which line the Atlantic coast. This study focuses on the AICW in the southern portion of the GTMNERR (Fig. 1). The AICW in the study area consists of a marked channel in the Matanzas River, portions of which have been deepened and straightened to provide enhanced navigation, and portions of which are completely man-made channel.

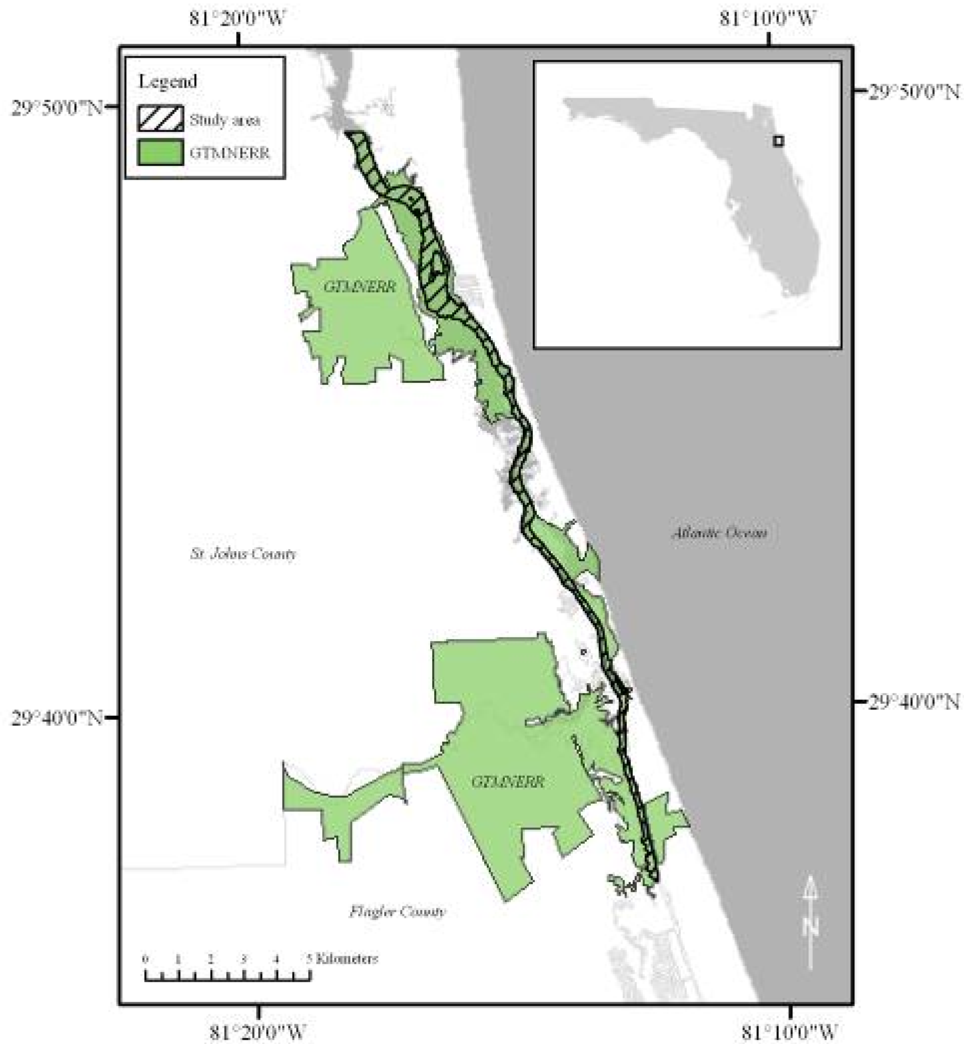

Fig. 1: Study area – Southern portion of Guana Tolomato Matanzas National Estuarine Research Reserve (GTMNERR)

Habitats found in the reserve include salt marsh and mangrove tidal wetlands, oyster bars, estuarine lagoons, creeks and rivers, dredge spoil disposal areas, upland, and a section of the adjoining Atlantic Ocean. It is of interest that the mangrove wetlands in the reserve constitute "the northern-most extent of mangrove habitat on the east coast of the United States" (Guana Tolomato Matanzas Reserve, February 18, 2004). The hydrology of GTMNERR estuaries has been significantly altered by human activities, including the construction of the AICW (Guana Tolomato Matanzas Reserve, 2004, February 18) which was first dredged as early as 1883 (Florida Inland Navigation District, 1967).

Years of personal observations and a brief pilot study conducted in the fall of 2003 made apparent the process of erosion and subsequent habitat degradation in the GTMNERR. The high rate of erosion observed in the GTMNERR appeared to be degrading natural habitats at a rate far faster than they could rebuild. Studies have shown that lateral erosion of salt marsh channels, such as that of the AICW and its tidal tributaries, is naturally offset by deposition in other areas (Letzsch and Frey, 1980). Thus, any observation of widespread erosion not offset by accretion elsewhere, warrants careful examination.

The margin of the AICW channel which runs through the reserve has eroded considerably over the past thirty years. As a result, highly productive habitats, including salt marsh, mangroves, and oyster bars, have been eroded and replaced by intertidal sand flats which are considerably less productive (Montague and Wiegert, 1990) and thus, potentially less valuable from an ecological perspective. The channel of the AICW in the GTMNERR is lined with tidal creeks, oyster bars, salt and mangrove marshes, dredge spoil islands, and developed uplands. The intent of this study is to (1) quantify the extent of habitat loss due to channel margin erosion from 1970 to 2002, (2) examine correlations between erosion rates and possible causal factors, (3) investigate management alternatives which could be used to limit erosion linked degradation at the AICW margin, and (4) examine the regulatory framework surrounding the implementation of such alternatives. Evidence suggests that boat wakes are the primary cause of observed erosion.

Background

The process of habitat loss to erosion in the GTMNERR can be described as erosion along the margin of a major estuarine channel which has been modified to provide for navigation. As displayed in Figure 2, the primary forces responsible for the movement of sediment are waves, currents, and human dredging and filling. Sediment supply regulates the amount of sediment available for accretion, and the sediment type and level of biological stabilization or destabilization govern the mobility of channel margin sediments. Of these factors, several can be disregarded as potential causes of the erosion in the GTMNERR and several are likely contributing causes. The role of sea level change is also addressed due to its connection to the global climate change debate and by association its application to coastal erosion.

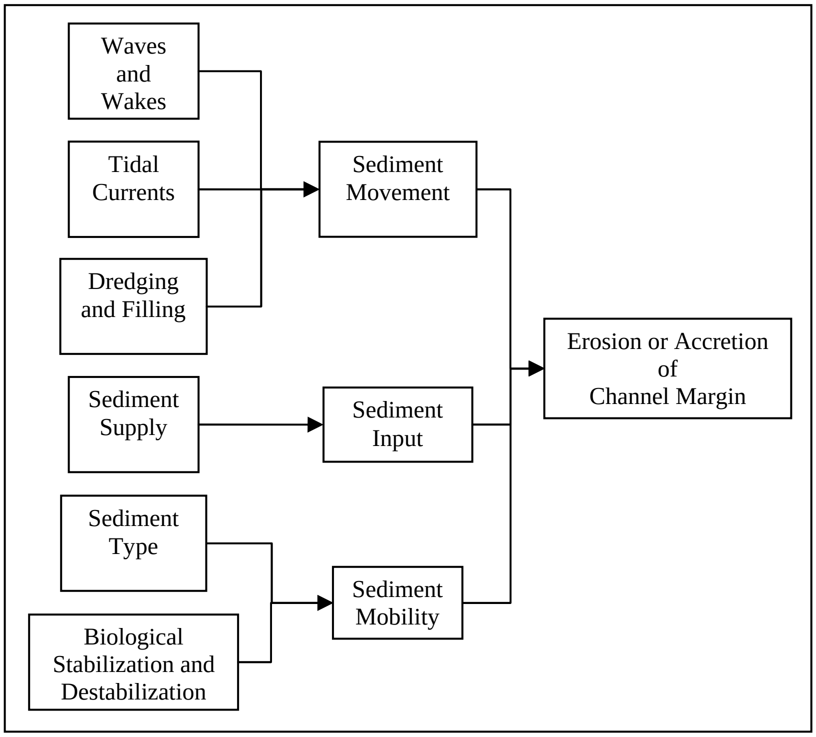

Fig. 2: Factors affecting erosion and accretion along an estuarine channel margin

Waves and wakes

In estuarine systems, the two major sources of wave energy are wind waves and boat wakes. Both are recognized as capable of causing significant sediment transport in a variety of aquatic environments.

Wind waves are cited as a cause of marsh erosion in a number of studies (Phillips, 1986b; Downs, Nicholls, Leatherman, and Hautzenroder, 1994; Day, Scarton, Rismondo, and Are, 1998; Doane, Wells, and Merman, 1998; Schwimmer, 2001). Waves erode the accumulation of peat under the stabilizing root mat of smooth cordgrass, *Spartina alterniflora*, the dominant marsh vegetation in the GTMNERR. This results in the episodic collapse of blocks of the marsh at the fringe. The unconsolidated sediments of non-marsh channel margins erode in a less sporadic manner. The prediction of the extent of wind wave erosion is difficult due to the number of factors which influence wave energy at bank impact. These factors include wind speed, duration and fetch (distance that winds blows over water), as well as water depth, influence of currents and angle of wave impact. Previous studies (Hershberger and Ting, 1996) have shown that even complex models of inshore wave propagation can encounter considerable error. Hershberger and Ting's research in the Gulf Intracoastal Waterway compared field measurements of wave height and period with those predicted by the U.S. Army Corps of Engineers (USCOE) Automated Coastal Engineering System model and found the model to over-predict waves when wind was blowing along the channel and under-predict waves when wind was blowing across the channel. Considerable expertise is necessary to accurately predict wind wave-caused erosion through the prediction of wave energy in a channel such as the AICW. A simpler predictor of channel margin erosion may be the presence or absence of exposure to causal factors such as wind waves.

Wind wave erosion has been found to be most severe downwind of the prevailing wind and largest local fetch (Downs et al., 1994; Day et al., 1998; Doane et al., 1998; Schwimmer, 2001). NOAA data from a coastal automated weather station approximately 2 km east of the study area show the predominant direction of winds over 10 knots from 1986 to 2001 to be from the north at 345^o to 45^o (National Oceanographic and Atmospheric Administration, 2003). The Beaufort wind scale defines 10 knots as the wind velocity at which small waves generally start to form and thus wind wave erosion can be expected to begin to occur. The severity of erosion can be expected to increase with increasing wind speed and storm events have the potential to cause rapid erosion.

During the study period northeast Florida experienced relatively few cyclonic storms. From 1970 to 2002 only 17 tropical systems passed within 65nm of Marineland, FL (the approximate center of the study area). Of these storms only one was a hurricane, eight were tropical storms, three were tropical depressions, two were subtropical storms, two were subtropical depressions and one was a tropical low. Only two storms impacted the northeast Florida coast directly, six passed offshore and nine made landfall elsewhere in Florida and exited into the Atlantic along the northeast coast. The three most powerful storms, Hurricane David in 1979, Tropical Storm Bob in 1985, and Tropical Storm Diana in 1984, with wind speeds of 85, 60 and 60kts respectively, all passed offshore. This suggests that their winds would come from a northerly direction like the predominant winds over 10 knots.

From 1986 through 2001 (the only portion of the study period for which local wind data is available) the northeast quadrant was not only the predominant direction for wind over 10kts, 59.7% of winds over 16kts were from the northeast, 77.8% of winds over 21kts were from the northeast and 90.9% of winds over 25kts were from the northeast (National Oceanographic and Atmospheric Administration, 2003). During this period, the study area was impacted by two tropical storms, three tropical depressions, a subtropical depression and a tropical low. Northeast winds were dominant during storm conditions as well as average conditions. This justifies the assumption that wind wave erosion along the Matanzas River will be most severe downwind of northeast winds, or along river channel margins facing north, from 90 to 300 degrees.

Boat wakes are also widely recognized as a cause of bank erosion in inland bodies of water (Zabawa, Ostrom and Byrne, 1980; Williams, 1993; Grossfeld, 1997; Maynord et al., 2001; Wilcox, n.d.; Kennish, 2002; Raines, 2003). Factors influencing the erosive impact of boat wakes include size of the generated wave, water depth, current direction and velocity, morphology of the impacted bank, presence of wind waves, and distance of the vessel from the shore (Macfarlane and Renilson, 1999). The size of the wake is governed by vessel speed, hull form, draft, loading, and trim. Generally, fast moving vessels displacing large volumes of water produce the largest wakes while vessels displacing less water and moving slowly or at planing speed produce the smallest wakes.

Wake-caused erosion can be distinguished from wind wave-caused erosion in that it occurs in areas sheltered from wind waves and may be most severe where the AICW channel is closest to the channel margin. Wakes can be expected to be a much more significant problem in the GTMNERR than in wider bodies of water. The relatively narrow channel of the AICW does not allow significant distance for wake energy to subside before wakes impact the margin. The narrow channel also does not provide as large a fetch for the development of wind waves as wider channels do; thus, ecosystems along the margins of the AICW are adapted to significantly lower energy levels than those along channels where larger wind wave propagation is possible. Personal observations supported by consultation with knowledgeable locals and experts in the field of coastal geomorphology (Sergio Fagherazzi, personal communication, 2004) have led to the hypothesis that boat wakes in the AICW are the primary case of channel margin erosion in the GTMNERR.

Tidal currents

Generally, river channels erode on the outside of bends, where current velocity and resultant shear stress is highest and accrete on the inside of bends. Tighter bends, with smaller radii of curvature, erode on the outside and accrete on the inside faster than wider bends with larger radii of curvature (Leopold, Wolman, and Miller, 1992). In stable systems lateral, current-induced erosion in one area is offset by accretion in another (Letzsch and Frey, 1980).

Dredging and filling

Dredging and filling for navigational or other purposes can cause erosion or accretion in several ways. Most obviously, channels can be dredged through an area or existing channels can be filled. This results in apparent erosion or accretion in a map or aerial photograph. According to Brian Brodehl of the USCOE Jacksonville district (personal communication, September 10, 2004), dredging can also cause channel widening when a channel is dredged to such a depth that when channel bed sediments reach their natural angle of repose, the bank is under cut. If the dimensions of a channel and the angle of repose of constituent sediments are known, it is possible to calculate the potential for erosion due to this mechanism. Considering that the planned dimensions for the AICW navigation channel are 125 feet wide by 12 feet deep and that the approximate angle of repose of bed sediments is 1:2.5 (according to B. Brodehl), the current mean width of the entire tidal channel, over 1000 feet, is more than sufficient to accommodate the construction of the channel without under cutting banks. Mr. Brodehl acknowledged that although the USCOE considers this calculation in the dredging of the AICW channel, it is likely that historically dredging efforts were not as carefully engineered.

It is also possible for dredging to alter depth or fetch available for wave propagation, or to alter current direction or velocity and thus indirectly influence local erosion rates. One mechanism through which channel dredging may increase current velocities and increase erosion rates is through alteration of the tidal prism (the difference in the volume of water in a water body between low and high tides) (Cox, Wadsworth, and Thomson, 2003). It is likely that dredging associated with the creation of the AICW altered the local tidal prism, but it is difficult to determine the magnitude of the change or to relate this change to sedimentary processes.

A second manner in which navigation related dredging and filling may have affected tidal currents, and thus affected sedimentation, is through the alteration of natural channels in the vicinity of Matanzas Inlet, both during the initial construction of the AICW and again in the 1970's. Figure 3 allows the comparison of the modern channel configuration with the unmodified channel, as depicted in United States Coast Survey maps created in 1867 and 1872. The channel to the north of the inlet was realigned during construction of the AICW channel as was the smaller channel running south from the inlet. The thin strip of land dividing the inlet and the navigation channel was also fortified to prevent tidal currents from depositing sediment in the channel. Together these modifications dramatically altered the natural tidal channels in the vicinity of the inlet and are likely to have caused substantial changes in sediment transport processes.