INLET-RELATED EROSION HOT SPOTS: MANAGEMENT AND ENVIRONMENTAL ISSUES IN SOUTHEASTERN NORTH CAROLINA, USA

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RESUMO
Toda costa urbanizada da parte sul do estado da Carolina do Norte (EUA) apresenta problemas relacionados à erosão induzida pela presença de canais de maré. O manejo dos processos ligados a esses canais tornou-se uma preocupação constante dos gerenciadores que precisam regular tanto a ocupação em áreas de risco parcamente delimitadas como a extração de areia. Todas as 15 comunidades desta área apresentam focos de erosão acelerada. Praticamente todos os canais de maré estão sendo alvo de modificações que envolvem realinhamento do canal principal e/ou dragagem dos corpos arenosos para extração de areia. Dados indicam que os canais de maré controlam os padrões de mudanças da linha de costa por 2-3 km ao longo das praias adjacentes. Independentemente do índice de estabilidade, todos os canais de maré são morfologicamente instáveis e têm a capacidade de promover alterações significativas através da complexa relação entre os movimentos do canal de vazante e as mudanças na forma do delta de vazante. Este trabalho relaciona as diferentes categorias de canais de maré, sua influência nas barreiras adjacentes e discute alguns exemplos de gerenciamento. Os dados representam canais de maré que se encontram em condições dinâmicas distintas, onde cenários de erosão e mitigação diferem grandemente.

ABSTRACT
All developed shorelines in the southern portion of North Carolina are experiencing problems related to inlet-induced erosion (hot-spots). Management issues related to tidal inlets have become a focus of concern for regulators due to the need to regulate development within poorly defined, inlet hazard zones and the utilization of sand resources. Erosion hot spots characterize all 15 of the oceanfront communities in the area. Almost all of the inlets have been targeted for modification that involves either realignment of the main channel and/or dredging of inlet-related sand bodies for sand resources. Data indicate that the targeted inlets control the shoreline change patterns for 2 - 3km along the adjacent shorelines. Regardless of the inlet's stability index all are morphological unstable and have the capacity to promote significant changes through complex linkages to movements of the ebb channel and the attendant shape changes in the ebb-tidal delta. The intent of this paper is to provide an overview of the different inlet categories, their influence on the adjacent barriers and management issues at exemplary sites. Data are presented from a number of distinctly different inlets within diverse coastal settings where erosion and mitigation scenarios differ significantly.

Palavras-Chave: variações da linha de costa, erosão acelerada, deltas de vazante
Key Words: Shoreline change, erosion hot-spots and ebb deltas

1. INTRODUCTION

The southeastern coast of North Carolina south of Cape Lookout consists of three distinct barrier/inlet groups that are separated by a submarine headland at New River Inlet and the subaerial headlands in the vicinity of Cape Fear (Fig. 1). Regressive barriers along the 70 km long shoreline reach between Cape Lookout and New River Inlet are sand-rich and are bordered by large stable inlets with relatively large ebb deltas. In contrast the 150km long sand poor, transgressive barrier segment to the southwest, is comprised of a reach that extends between New River Inlet and the subaerial headland at Fort Fisher and a second that extends westward from the subaerial healand at Yaupon Beach to the jetties at Little River, South Carolina. Collectively this latter group of barriers, are narrow, low, and bordered by a variety of stable and migrating inlets with small ebb deltas.

It is generally recognized that almost all of the chronic erosion zones within southeastern North Carolina are associated with contemporary inlets or historic inlets that have been artificially closed. All developed shorelines in the southern portion of the state are experiencing problems related to inlet-induced erosion (hot-spots), and as such, have drawn the attention of local and state governmental agencies and environmental advocates as communities attempt to mitigate the rapid land loss. Management issues related to tidal inlets and their associated environmental impacts have become a primary focus of concern for coastal regulators in North Carolina due to the state's need to regulate development within existing, poorly defined, inlet hazard zones and the utilization of inlet sand resources. Eighteen of the 22 diverse inlets that occur along the coastline are located in the study area and 13 of these border developed shorelines (Fig. 1). Three of the inlets have closed within the past seven years. Most existing inlets have a history of some form of modification ranging from interior channel maintenance to complete stabilization involving extensive dredging or jetties. Erosion hot spots characterize all 15 of the oceanfront communities in the area. As a consequence, almost all of the inlets regardless of size have been targeted for modification that involves either realignment of the main channel to stem the land loss and/or dredging of inlet-related sand bodies for resources for beach fill projects. Ongoing studies indicate that the targeted inlets control the shoreline change patterns for 2 - 3km along the adjacent oceanfront shorelines.

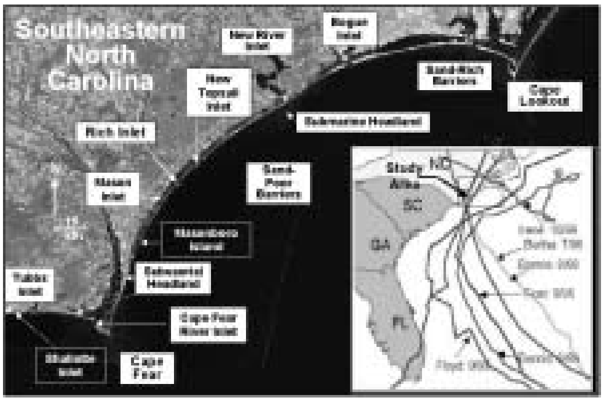

Figure 1 – Location map of study area depicting major features, inlets and tracks of recent hurricanes.

These diverse, wave-influenced transitional inlets (Figs. 2 - 4) range in terms of locationally stability from highly unstable systems such as Mason, New Topsail and Tubbs Inlets (Fig. 3) to relatively stable features such as Bogue, Rich and Shallotte Inlets (Figs. 2 and 4). However, regardless of their stability index all are morphological unstable and have the capacity to promote significant oceanfront shoreline changes through complex linkages to movements of the ebb channel and the attendant shape changes in the ebb-tidal delta. A number of coastal communities are dealing with critical management issues that concern the chronic and often cyclical erosion that is characteristic of these dynamic inlets and their associated hazard zones.

The intent of this paper is to provide an overview of the different inlet categories, their influence on the adjacent barriers and management issues at exemplary sites. Data are presented from a number of distinctly different inlets within diverse coastal settings where erosion and mitigation scenarios differ significantly. The GIS database for this study consisted of approximately 20 to 50 sets of historic aerial photographs dating from 1938 to 2003. The historic aerial photographs were digitized and rectified for each inlet and measurements made along a series of baselines for the determination of inlet and oceanfront shoreline and ebb delta changes. These data were integrated for each inlet for the purpose of tracking the linkage between the ebb channel, ebb delta and oceanfront shoreline changes, specifically the development of the different types of inlet-induced erosion hot-spots. Analyses of the data sets indicate the following generalizations apply to the inlets within the study area.

2. STABLE INLET SHORELINE CHANGES AND EROSOION HOT SPOTS

Shoreline change patterns along stable inlet shorelines were related to cyclical changes in the symmetry of the fronting ebb tidal deltas. The cycles were associated with repositioning and realignment of the outer bar channel and the corresponding position changes in the marginal flood channels. The consequences of ebb delta reconfiguration are twofold: first and foremost large swash bar complexes are no longer able to nourish the developed segment of the shoreline; secondly the highly asymmetric ebb-tidal delta no longer affords protection to the exposed barrier from wave attack (Figs. 2 A and C, Fig. 4 B). Consequently, rapid erosion becomes the norm. Cycles are of variable length and range from six to thirty years; cycle length is a function of inlet size and storm history. Cycles are shortened by storms and were typically much longer at larger inlets. The northern 1.5km of Figure Eight Island that borders Rich Inlet has eroded more than 170 m between 1997 and 2002 due to the deflection of the ebb channel and the corresponding reconfiguration of the ebb delta (Fig. 2 C). The erosion hot spot coincides with a former accretion zone that is currently fronted by extensive sand bags that protect 15 homes valued at 50 Million USD. Similarly a 1.5 km long erosion hot spot has developed in the past decade on the downdrift shoulder of New River Inlet where numerous mitigation efforts have failed to stem the land loss and many homes are threatened (Fig. 2 B).

The deflection, extension and eventual abandonment of the ebb channel across the outer bar provides a mechanism whereby sand packets of varying size are periodically bypassed to the adjacent oceanfront shorelines. At most stable inlets the swash bar complex is bypassed to the downdrift shoulder as a consequence of ebb delta breaching, however, in some cases the packet can be bypassed updrift depending upon the orientation of the channel, breach site and the ebb delta shape. Bald Head Island, the barrier adjacent to the Cape Fear River Inlet, accreted more than 800m between 1885 and 1915 following an ebb delta- breaching event that released more than 4 million m^3 of material to the downdrift shoulder (Fig. 4 A). This scenario predated the major stabilization of the harbor entrance ship channel. In April 2003 a breach occurred in the highly asymmetric ebb-tidal delta of Rich Inlet. If the ebb channel eventually realigns and occupies the the breach site, more than 6000,000m^3 of sand will be bypassed downdrift to the Figure Eight Island oceanfront signaling a reversal of the recent erosion episode.

3. INLET MIGRATION INDUCED SHORELINE CHANGES

The rates of migration of unstable inlet systems are highly variable and are generally a function of the tidal prism that is dependent upon the hydraulic conditions of the soundside feeder channels. Shoaling within the back-barrier area has led to the closure of three long-lived inlets within the past decade. Closure has resulted in longer barriers with different planforms. All contemporary unstable inlets with the exception of Tubbs Inlet are migrating downdrift to the SW or W depending upon the setting at rates that range form 7.0 to 45m/yr. In addition to the erosion of the downdrift barrier, migration has resulted in the truncation and realignment of the updrift trailing shoreline (Fig. 5). Erosion rates along some updrift reaches such as along Topsail Beach, that borders New Topsail Inlet (Fig. 3 A), and along the southern portion of Figure Eight Island that borders Mason Inlet (Fig. 3 B), were as high as 12m/yr for a decade.

Concurrent with migration, packets of sand bypassed the updiift shoulder of the inlets when ebb deltas were breached. The cycle of ebb delta breaching varied in length from 2 to 20 years. Deflection of the channel in an updrift direction and the eventual realignment of the ebb channel and simultaneous changes in the symmetry of the ebb delta caused migration and attachment of small bar complexes (100 m x 50 m) within one km updrift of the main channel.

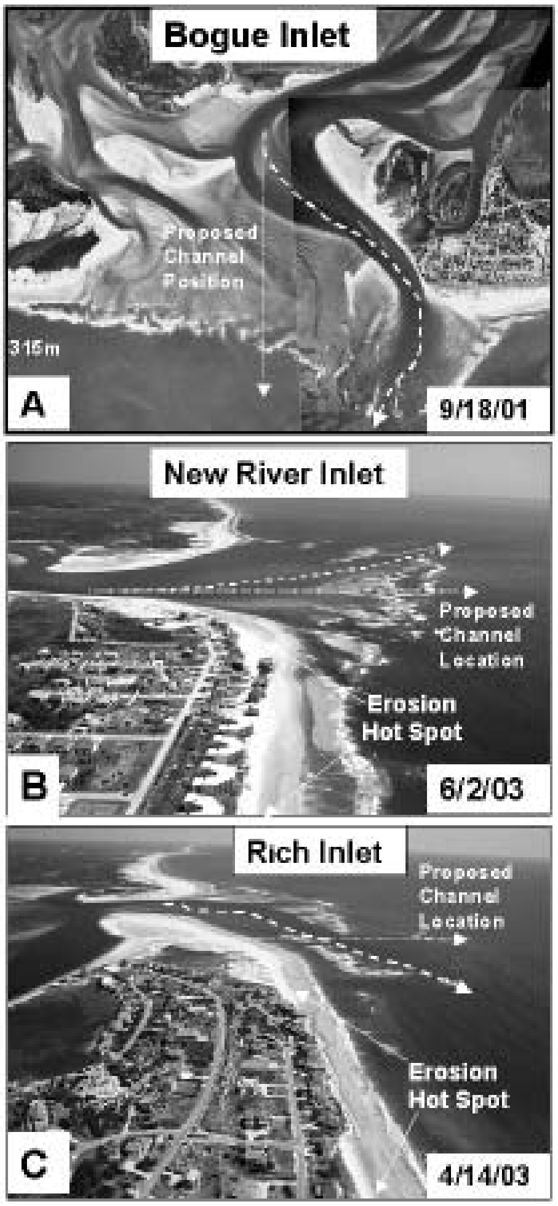

Figure 2 – Aerial photographs depicting locationally stable inlets and associated erosion hot spots. Ebb channel locations are indicated by arrow

The sand packets frequently prompt periods of relatively rapid inlet migration as the bars move laterally along the barrier spit and into the adjacent estuary. New Topsail Inlet is an exemplary site where this mechanism has been documented (Fig. 3 A).

4. TARGETING INLETS FOR BEACHFILL MATERIAL

Although the shoreface has been viewed as a borrow source for the eroding oceanfront beaches, data indicate it has a low potential for providing sand nourishment programs. As a consequence, all communities have targeted tidal inlet systems for sand. However, stringent environmental restrictions involving sand mining within estuarine waters precludes the use of flood tidal deltas for beachfill. Consequently, more costly efforts involving ebb tidal delta modification have been proposed.

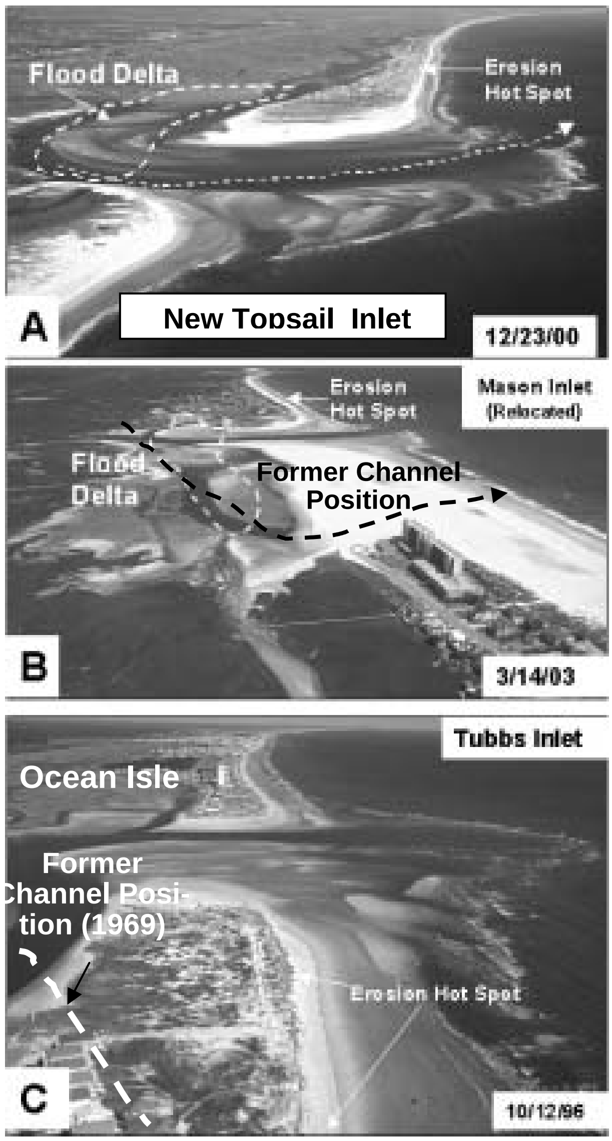

Figure 3 - Aerial photographs of unstable (migrating) inlets. Ebb channels are indicated by arrows and flood deltas are delineated by dashed lines.

Although generally viewed as the only likely long-term borrow sites, alteration of inlets bordering developed shorelines is a politically controversial and environmentally sensitive issue. Modification of the ebb tidal delta without a detailed site-specific understanding of the linkage between the shoals and the adjacent shorelines will result in significant changes in the entire sand sharing system. Depending upon the scale of dredging and the attendant morphologic change, erosion along the downdrift beaches will follow as channel and bar complex repositioning occurs during post-dredging reconfiguration of the ebb tidal delta. The re-alignment of ebb channel at Shallotte Inlet (Fig. 4 C) to a mid throat position will shift the location of the erosion hot spot from the updrift shoulder to the downdrift shoulder where 50-90m of erosion will occur on the downdrift shoulder. Similar channel relocation efforts are proposed for Bogue, New River and Rich Inlets (Fig. 2 A and C).

5. IMPACT OF LARGE SCALE INLET MODIFICATION

Data from a number of inlets indicate that modification by dredging resulted in an increase in tidal prism, a correspondingly larger retention capacity of the ebb delta and disruption of the natural ebb delta breaching cycle. Dredging impacts are reflected in an extension and deepening of the ebb channel across the ebb platform. Bypassing to the downdrift shoals ceased or is dramatically reduced when the ebb delta is bifurcated during channel maintenance. Typically, the maximum rate of erosion will lag the breaching of the shoals by several decades, especially in the larger inlets such as the Cape Fear River Inlet (Figs. 1 and 4 A). South Beach on Bald Head Island at the entrance to the Cape Fear River continues to erode due to the stabilization of the ship channel that occurred in the early 1900s. Inlet stabilization by jetties mimicked the impacts of dredging. Significant coastwise erosion associated with inlet modifications is exemplified by Masonboro Island, a 13 km long barrier (Fig. 1). Located between a jettied system and a continually dredged artificial inlet, Masonboro Island has experienced an increased rollover rate due to the major reduction in sand supply. The recent storms combined with the reduced sand supply have led to an increase in washover topography along 100% of the island's length.

Several small migrating inlets have been relocated in the area during the past 30 years. Tubbs Inlet (Fig. 3 C), that forms the eastern border of Sunset Beach, had a complex history related to the relocation of the inlet in 1969 and the associated changes in the lagoon hydraulics. During past 200 years the inlet migrated westward along a 2km long shoreline reach. In December 1969, Tubbs Inlet was relocated approximately 1km to the east. The new location approximated the inlet’s 1938 position. Subsequent to relocation and after a period of adjustment, the inlet began migrating to the east opposite its historic migration trend and the regional net littoral drift. Presumably dredging of principal western feeder channel altered the hydrodynamics of the lagoon, redirecting the majority of the ebb flow toward the eastern shoulder (Ocean Isle). The current position of the inlet continues to promote shoaling within the eastern backbarrier channel and increased rates of migration due to a further reduction in the tidal prism. As a consequence, the oceanfront along the eastern portion of Sunset Beach has experienced increased erosion as the planform of the barrier continued to realign in accordance with the easterly trek of the inlet and the consequent repositioning of the ebb-tidal delta (Fig. 5). The Town of Ocean Isle has plans to dredge the eastern feeder channel in an attempt to restore the hydraulic connection of the channel that would help offset the easterly migration of the inlet and the erosion of the western portion of the barrier. The controversial project has been met with stiff resistance by governmental regulators and environmental advocacy groups.

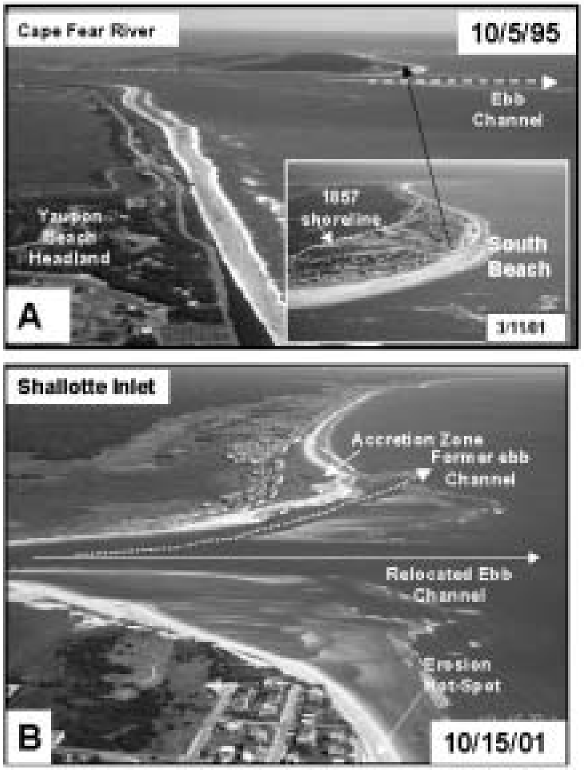

Figure 4 – Aerial photographs of stable inlets where the ebb channel has been relocated.

Mason Inlet, the second inlet to be relocated in the area, is a small unstable inlet (Figs. 1 and 3 C) that has been the focus of a variety of environmental and management issues since 1995 when the rapid erosion of the downdrift Shell Island shoreline threatened to undermine the 25 million dollar Shell Island Resort. Between 1990 and 1996 the rates of inlet migration more than doubled (50m/yr to 100m/yr). The dramatic increase in migration rates reflected the drastic reduction of the inlet’s tidal exchange capacity due to sedimentation in the backbarrier tidal channels, the southerly migration of the inlet and the concomitant increase in the relative importance of the littoral processes. In early 1997 the southern inlet margin was hardened with sandbags to protect the infrastructure and the resort complex. After considerable debate, due to the environmentally sensitive nature of the issues related to the relocation efforts and the perceived economic ramifications for the county, a new inlet corridor was excavated in March 2002 updrift across Figure Eight Island, ~ 900m north of the existing inlet.

Measures taken to increase the tidal prism of the new inlet included dredging the backbarrier primary channel connections. A settling basin was also dredged to help prevent rapid shoaling that is a product of flood-tidal delta formation in this flood-biased system. The sediment dredged from the interior channels was used to close off the old inlet and nourish a 2,600 m segment of southern portion of Figure Eight Island (Fig. 3 C). During the past 14 months significant shoaling has occurred in the sedimentation basin and adjacent navigable waterways that has necessitated dredging of the portions of the interior channels. The southern end of Figure Eight Island is also experiencing erosion as the newly relocated inlet is adjusting to a larger tidal prism and is sequestering sand on an enlarging ebb-tidal delta. These events were not predicted and have caused a variety of concerns related to the success of the project and the increased costs to maintain the inlet in its present position.

Despite increased knowledge concerning the natural process of change associated with inlets, management of these systems is difficult due to the magnitude of change caused by either natural or man induced processes and is impossible to predict with sufficient accuracy to assist coastal mangers in making sound decisions. Therefore each inlet must be studied in detail to ascertain the specific magnitude and direction of change and its effect on human occupation and commerce. The decade to century scale coastwise sand budget and ultimately the shoreline retreat rates are negatively affected by the increased retention capacity of modified inlets.

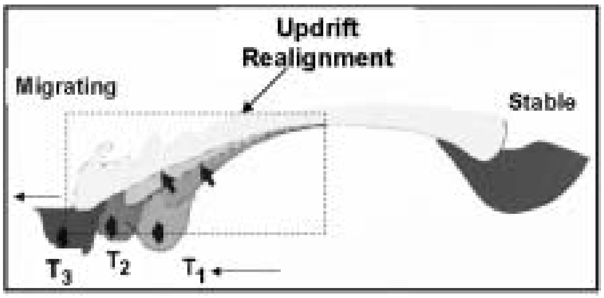

Figure 5 – Cartoon depicting updrift planform readjustment as a consequence of inlet migration.