ANALYSIS OF BEACH NOURISHMENT DATA FOR FLORIDA'S ATLANTIC COAST DURING THE LAST CENTURY, WITH REFERENCE TO ECOLOGICAL ENGINEERING OF SEA TURTLE NESTING HABITAT

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Abstract

Beach nourishment has not been a proactive tool for rebuilding lost sea turtle nesting habitat, yet much habitat may be missing owing to beach erosion caused by the long history of harbor and inlet engineering. To estimate the potential loss of nesting habitat, a century of dredge and fill data for the east coast of Florida was extracted from two online databases (US Army Corps of Engineers and Duke University). The records show removal of over 150 million cu yd of material from the sand budget by disposal at offshore and at upland sites. The volume of harbors and channels was increased by a little over 62 million cu yd. Little of the lost material has been returned, and much of the remaining sand has become redistributed, with a possible loss of dunes and the dry berm in which sea turtles build nests. Allowing the deepened harbors and inlets to refill may further erode beaches and dunes. Assuming the depth is maintained, and that 30% of the material removed was never part of the sand sharing system in the first place, in 2003 a sand deficit remained of a little more than 60 million cu yd. This is enough sand for a layer 2 yd deep, 100 yd wide and 185 miles long. Improvements in engineering theory and practice and diligence on the part of sea turtle managers have reduced the short term impacts on turtles, and increased the durability of restored beaches. It may now be appropriate to incorporate beach nourishment as a tool in the restoration of critical nesting habitat for sea turtles. Replacing the amount of sand missing may restore all currently unsuitable nesting beaches to full sea turtle production capacity. Finding enough sand of appropriate quality to import into the system is an immediate concern. The increasing cost of fuel is another. Failure to act now may mean the opportunity for humanity to restore sea turtle nesting habitat will be lost.

Introduction

Sea turtles are among the truly spectacular species on earth and much effort goes to ensure their survival. Animal species often become endangered because critical habitat has declined as people and economic development intrude. Sea turtle nesting habitat is the dry berm on sandy beaches near the base of the foredune. The location of the dry berm is illustrated in Figure 1. Figure 1 also shows the major accumulations of sand in the coastal sand-sharing system, and some changes to these, including beach erosion, that may have occurred over the history of harbor and inlet dredging. The Atlantic coast of Florida is among the world's coastlines most frequented by gravid female sea turtles in search of nest sites. When beaches erode along the Atlantic coast of Florida, rock is often exposed because of the proximity of the Anastasia formation just under the veneer of sand (Davis 1997). In addition, rock revetments and seawalls are often placed on the beach to retard erosion of uplands. Exposed rock, revetments, and seawalls have replaced sea turtle nesting habitat in many places on Florida's coast.

Although barrier beaches are migrating steadily with sea level rise, the beach face erosion caused by this long term process by itself may not be a major contributor to loss of nesting habitat by sea turtles. The time scale is long, and if the only factor is rising sea level, all parts of the sand-sharing system remain relatively constant (Dean and Dalrymple 2002). However, construction and maintenance of harbors and inlets could have increased beach erosion and reduced sea turtle nesting habitat in a much shorter time frame by: a) removing sand from the sand sharing system; and b) shifting the distribution of sand among its major accumulations. These processes are illustrated in Figure 1. Dredged sand has often been physically transferred out of the sand sharing system to upland disposal sites or to offshore areas beyond the "closure depth." Closure depth (h_c in Figure 1) is a depth that defines the edge of the sand sharing system for the engineering time frame (for a discussion, see Dean and Dalrymple 2002). It is this time frame over which losses of sea turtle habitat caused by engineering projects have occurred, and over which these losses can conceivably be corrected.

Although onshore winds and breakers effectively retain sand shoreward of the closure depth, the distribution among major sand accumulations may shift simply because gravity is a persistent force. Gravity will move sand from high elevations to lower ones and from shallow areas to deeper ones. Dredged sites, for example, become sand traps that are continually redredged to maintain safe and navigable inlets and harbors. Hypothetically, at least, if not actively replenished, the ultimate source should be the highest elevation sand within the sand sharing system, namely the dunes and dry berm where sea turtles deposit their eggs. The process is illustrated in Figure 1.

Jetties should exacerbate such losses of beaches and dunes. They are built in part to intentionally direct sand to specific accumulation sites. Long jetties redirect the longshore drift of sand out to deep water just beyond the natural ebb shoal. This builds a deeper ebb shoal in another place, or below the design channel depth, presumably helping to keep the artificially deepened inlet channel from refilling as quickly. Like the filling of dredged harbors and channels, the new shoal is also built at the expense of the highest elevation portions of the sand sharing system, namely the dunes and dry berm, as illustrated in Figure 1.

In addition, of course, dunes may have been leveled and removed during preparations for beachfront building construction. This process would be another pathway for removing sand from the sand sharing system and storing it on land. Protecting that land from erosion also keeps the sand from reentering the sand sharing system.

Accordingly, removal and redistribution of sand may have accelerated beach erosion well beyond that attributable to the slow process of barrier island migration. Unlike the natural unimpeded movement of barrier islands as sea level rises, these alterations to the sand sharing system can cause a loss of sea turtle nesting habitat, and the loss of dunes. A dune field is not only a storm barrier that protects leeward uplands, dunes buffer and rapidly resupply sand to the dry sand berm as it annually erodes during routine winter storms. In this way, dunes secure the presence of sea turtle nesting habitat at the beginning of the next sea turtle nesting season.

Eroded sea turtle nesting habitat may be artificially restored by continually shifting sand back to the beach and dunes, or by removing the causes – depleted sand in the entire system, and jetties that redirect sand to deeper water. Returning sand to the sand-sharing system, however, means importing it from offshore and upland sources.

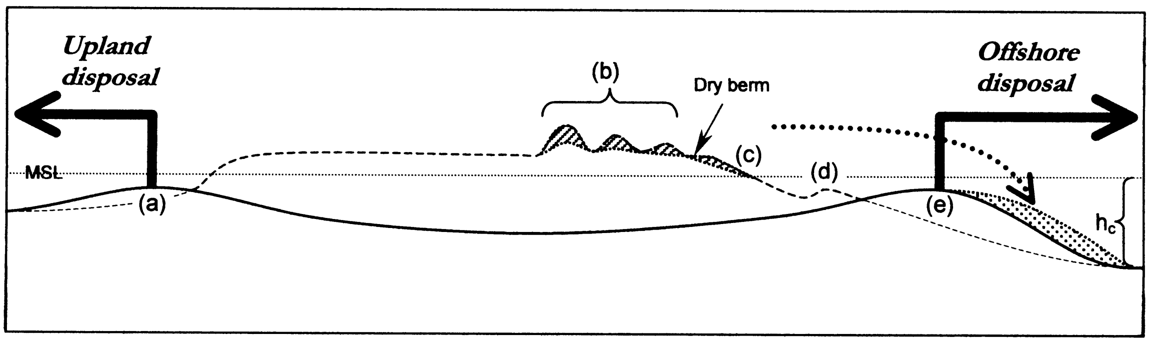

Figure 1. Cross-section of an inlet from estuary (left) to ocean (right) illustrating five major sand accumulations within the sand sharing system, and a hypothetical response to offshore and upland disposal of dredged material and to the construction of jetties: a) flood shoals, b) dune fields, c) beaches, d) sand bars, and e) ebb shoals. Heavy arrows indicate complete removal of sand from the system via harbor and inlet dredging. Barrier island profile represented by a dashed line, inlet-shoal profile by solid line. Mean sea level (MSL) indicated by dotted horizontal line. Closure depth = h_c. Sea turtle nesting habitat is the dry berm at the base of the foredune. Hypothesis: some material from dunes and beach (hashed area) is transferred to the seaward slope of ebb shoals (stippled area) as sand-sharing system adjusts to sand deficit and jetties direct longshore drift to ebb-shoal. Result is less nesting habitat.

Oddly, restoring lost sea turtle nesting habitat was not mentioned in the National Research Council's report on marine habitat restoration (Sands et al. 1994). Although it is widely recognized that sea turtles themselves cannot nest on badly eroded beaches (*e.g.*, Nelson and Dickerson 1988, Wolf 1988), little or no demand has arisen for beach nourishment as a means of restoring lost nesting habitat for sea turtles. In fact, efforts to restore eroded beaches often have been met with resistance from sea turtle managers (*e.g.*, see contributions from sea turtle managers in Montague and Chesnes 2003). Unwitting damage to sea turtles – both documented and potential – from attempts to restore eroded beaches has perhaps driven resistance to a process that could become a tool to ecologically engineer sea turtle nesting beaches (as outlined in Nelson and Dickerson 1988 and Montague 1993 for example).

Reasons for a lack of proactive habitat restoration for sea turtles are not clearly identified in literature, but would be rational if damage to sea turtles from the process of building habitat is in fact greater than the survival value afforded the species by having the increased habitat. At the extreme, this could be true if the quantity of suitable nesting sites were in excess of that needed for nesting success – in other words, if sea turtle nesting habitat was not in fact critical to sea turtle survival. This seems unlikely. On the other hand, if sea turtle survival as a species is linked to habitat availability, and if levels of nesting habitat before coastal development were much higher than now, then restoration of nesting habitat to natural levels would be a management imperative that must be weighed carefully against the short-term damage caused by the process of restoring the habitat. Determining the magnitude of the loss is a first step in making such an evaluation.

An analysis was undertaken to determine the amount of sand that may have been removed or relocated from the sand sharing system during the century-long history of dredge and fill operations on the Atlantic coast of Florida (Montague, unpublished manuscript). Relevant results of this analysis are discussed below in the context of evaluating beach nourishment as a tool for restoring sea turtle nesting habitat.

Analysis of the Record

Dredging records posted on the internet by the US Army Corps of Engineers (2004, herein referred to as the USACE database) and beach nourishment records posted by Duke University (2004) allowed reconstruction of the quantitative history, dynamics, and cumulative impacts of dredge and fill operations on the Atlantic coast of Florida. In combining the two databases irrelevant and duplicate records were removed, and entries checked where possible using independent references (Montague, unpublished manuscript). From the corrected combined database, annual and cumulative total volumes of sand dredged and total volume of fill deposited in various locations were calculated and plotted over the period of record (Montague, unpublished manuscript). The USACE database includes only federally funded projects involving harbor and inlet dredging. Disposal locations given in the USACE database include categories identified as offshore, nearshore, beach, upland, or other. The Duke University database includes all projects in which sand was placed on the beach and thereby extends the USACE information by including locally funded inlet management projects and projects done solely for beach nourishment (rather than as a part of inlet or harbor construction or maintenance). In nourishment-only projects, the sand was derived from dredging nearby shoals, or was imported from upland or offshore sources. Although only those inlet-dredging projects that placed material on the beach are included in the Duke database, beaches are apparently the only sites that have been used for disposing of dredged material in non-federal inlet management projects along the Atlantic coast of Florida.

The history covered by the combined database spanned from 1903 to 2003. It began with dredging Fernandina Harbor (St Marys Entrance) at Florida's border with

Georgia, followed in 1905 by dredging of Miami Harbor at the southern end of Florida's Atlantic coast. During the first decade of dredging, 961 million cu yd were dredged from Fernandina Harbor, and another 485 million cu yd from Miami Harbor. The earliest record of beach nourishment included in the database was the addition of 0.28 million cu yd to the beach south of Lake Worth Inlet in 1944. Dredging and disposal activity increased considerably after World War II, peaked between 1970 and 1990 and subsequently declined. Disposal of dredged material in offshore and upland sites was apparently the general practice prior to 1970, and remained a very common disposal practice through the 1980's. Beach and nearshore disposal dramatically increased after 1970 and became the primary disposal practice after the 1990's (Montague, unpublished manuscript).

Overall, during the century from 1903 to 2003, a total of 210 million cu yd of material were dredged in navigation projects in which harbors and inlets were built, improved, deepened, and maintained along the Atlantic coast of Florida. Of this, roughly 62 million cu yd was for harbor and channel expansion and deepening (identified as "new work"). The rest was for maintenance dredging necessary to maintain the new depth. In both of these types of work, however, over 70% of the material – a cumulative total of 152 million cu yd – was disposed either offshore or at upland disposal sites. Only 35 million cu yd (17%) of the material dredged in navigation projects over the last century was placed near or on shore. The remainder (23 million cu yd) is of unknown disposition.

A total of 275 million cu yd of material were deposited along Florida's Atlantic coast, for an excess fill of 65 million cu yd over that attributed to navigation projects. Planned or emergency beach nourishment projects account for this excess. The source of the nourishment sand is not specified in the data base, however most was dredged from nearby shoals or sand traps. A small amount is known to have been trucked in from upland sources, or barged from sources beyond the Atlantic coast of Florida. This is a most important distinction because nearby shoals are within the sand-sharing system. Moving sand around within the sand sharing system does not overcome the deficit. Only by importing sand can the deficit be restored.

Discussion

Assuming the material reported to have been disposed offshore or upland was effectively removed from the sand sharing system, a gross deficit of 152 million cu yds can be attributed to the effort over the last century to improve inlets and harbors. If the dredged material of unknown disposition escaped the sand sharing system, the gross deficit would be 185 million cu yd. This total could be revised downward to the extent that:

a) the sediment originally dredged and disposed offshore or upland was not actually a part of the sand-sharing system at the time it was removed;
b) the sand of unknown disposition remained in the sand-sharing system;

c) beach nourishment has been done with material brought into the sand-sharing system from offshore or upland sources outside the sand-sharing system, rather than from shoals, traps, and updrift beaches within the system; and
d) artificially deepened channels and harbors are maintained so that they do not begin to fill in again (with sand from the sand sharing system).

A reasonable minimum estimate for the deficit must be based on assumptions about these factors. An example is given in Table 1, where the estimated deficit is roughly one-third of the maximum given above. Inasmuch as the adjustments are generous, this estimate could be considered a minimum. In addition, the estimate would be revised upward if some of the sand placed "nearshore" was in fact not completely retained within the sand-sharing system.

Table 1. Adjusted estimate of the cumulative sand deficit caused by offshore and upland disposal of dredged material in navigation projects between 1903 and 2003.

Sand volume (million cu yd)	**Meaning**
185	Worst case estimate of sand deficit *unless* some nearshore disposal was beyond the closure depth (removed + unknown disposition).
152	Volume of sand removed from system.
23	Volume of sand of unknown disposition.
65	Volume of nourishment projects.
62	Volume of artificially deepened harbors and channels.
Assumptions	
	30 % of sand removed that was not in the system in the first place.
	50 % of sand of unknown disposition remained within the system.
	2 % of nourishment sand came from sources outside the system.
	99 % of artificial deepening is maintained (not allowed to fill in).
Adjustments made from above assumptions (million cu yd)	
45.6	Volume of sand removed that was not part of sand sharing system.
11.5	Volume of sand of unknown disposition that never left the system.
1.3	Volume of sand restored to system via nourishment projects.
61.4	Remaining volume of artificially deepened harbors and channels.
119.8	Total revisions to worst case deficit.
65.2	***Revised estimate of sand deficit.***

Nevertheless, the amount of the revised sand deficit given in Table 1 is equivalent to a layer of beach sand 2 yd deep and 100 yd wide added to 185 miles of Florida's coast. Such a deficit implies a considerable amount of missing sea turtle habitat. If the missing sand were returned to the sand-sharing system, sea turtle nesting habitat would seem likely to be considerably enhanced over present levels, and better buffered against storms. The amount missing would seem to be enough sand to eliminate any and all parts of beaches along Florida's east coast that nesting sea turtles cannot presently use because of hard surfaces, natural or otherwise.

In addition to the large sand deficit, rapid growth has occurred in some ebb shoals and the quantity of sand stored in the beach face has declined (Dean and O'Brien 1987). Although volume change data were not included for all ebb shoals on Florida's Atlantic coast in Dean and O'Brien (1987), the total growth among those reported was roughly 170 million cu yd. The growth occurred over a period of a few years for some shoals to several decades for others. The source of the sand in the shoals was apparently not entirely from the beaches. The reported decline in beach volume was only about 28 million cu yd (Dean and O'Brien 1987).

The difference of over 140 million cu yd between beach volume decline and ebb shoal growth could conceivably be derived from the erosion of dunes if dunes were not included in the beach profiles on which beach volume change was based. One reason this could happen is because the profile transects did not extend into the dunes. A more insidious reason could be that the dunes were already gone prior to the first measurement of volume. In any case, the volume difference is equivalent to an average 10-foot high dune system of three dunes deep (including the foredune) along nearly 300 miles of coastline (Montague, unpublished manuscript). The Atlantic coast of Florida today has few dunes, and perhaps little information is available about the historical amount of dunes before coastal development and jetty construction.

The major input of sand to Florida's Atlantic coast is thought to be longshore drift from the north (Dean and O'Brien 1987). The amount reported to cross the Georgia-Florida boundary 0.5 million cu yd per year. Proceeding south along the coast, most of this sand apparently disappears. It is thought to pass offshore into deep water (Finkl 2004). Alternatively, it could disappear because it settles within the sand-sharing system, slowly replacing the deficit left by offshore and upland disposal of dredged material over the past century even as jetties direct it to newly forming ebb-shoals. To restore 65 million cu yd of cumulative deficit this way, however, would require at least 130 years, assuming the expected amount actually arrives from Georgia, and then only if none of the drifting sand slides into deep water.

In 1988, Bodge reported a cumulative total of 63 million cu yd of upland and offshore disposal along the Atlantic coast of Florida (Bodge1988). The amount is roughly half that reported through 1987 in the combined databases used here. Of the discrepancy, 75% is attributable to a much greater volume of offshore and upland disposal recorded for projects involving Jacksonville and Mayport Harbors than was reported for Duval County by Bodge. Nearly all the remainder involves material disposal from projects at Canaveral Harbor (10%), Port Everglades Harbor (10%), and Miami Harbor (5%).

The difference in volume reported is a tribute to the value of the USACE and Duke University efforts to compile records into an online database. Piecemeal reconstruction of dredging and disposal records is prone to underestimation because it can be difficult to know if all relevant records have been found. The accumulation and open posting of these data may have many other valuable uses never imagined by the compilers. The independent examination of the data by any interested party offers a mechanism to continually correct and update records. Independent analysis of the information may produce unexpected results that can reduce future costs, or allow harbor, inlet, and beach engineering to more effectively respond to multiple objectives.

In this regard, with respect to sea turtle management, a database of all nesting records on Florida's Atlantic coast should be directly relevant, especially those collected specifically to assess beach nourishment effects.. This information has been collected as a matter of course for beach nourishment projects over many years. The costs of both collecting this information in the first place and compiling it could perhaps easily be repaid through the exposure to independent analysis that a resulting online database can receive.

Conclusions

The potential for using beach nourishment proactively for sea turtle management has been enhanced by improvements in beach nourishment engineering theory and practice. These improvements have occurred over the years partly in response to diligent concern by sea turtle managers over damage to sea turtles (e.g., Nelson et al. 1987, Nelson 1991, McNair 1992). The needs for acceptability by beachgoers and especially for durability of nourishment projects have also stimulated improvements relevant to proactive sea turtle management. Increasingly with beach nourishment practice, damage to sea turtles seems less, the period of interference with nesting shorter, and the duration of enhanced nesting success longer (*e.g*., Wolf 1988, Palm Beach County 2002). Now – with continued diligence on the part of sea turtle managers and with appropriate attention to details such as sand quality, application method, and timing – restoration of historical levels of sea turtle nesting habitat is conceivable.

With information already available, future projects could also provide substantially greater durability of beaches and could remove immediate post-project instability of restored nesting habitat. For example, durability should be vastly improved by larger scale nourishment projects (Dean 2002). Moreover, if profile nourishment of the *breaker zone* (Bruun 1989) were the method of choice, instead of application directly on the beach face, post-project stability of nesting habitat could theoretically be similar to that of a natural beach. The result might justify the extra patience required to build a beach this way. Finally, by building dunes, sea turtle nesting habitat should be able to endure routine annual cycles of natural erosion and rebuilding.

Restoring high quality sea turtle nesting habitat will be increasingly expensive as the price of fuel rises, and as suitable source material becomes more difficult to find, yet the intrinsic value of sea turtles may justify the effort. Large, slowly growing species are enormously valuable when weighed against the amount of nature's work involved in their evolution. According to "emergy" theory (Odum 1996), an ecologically-based valuation method, the effort of nature to produce sea turtles (*i.e*., the energy naturally used to power the processes involved) may well be a measure of their relative influence and value within the system of nature of which people are also a part. The work of nature involved in each individual sea turtle is substantial, but pales in comparison to the resources involved in the evolution of such a species. In that effort can be found the replacement cost of extinction. Even without a formal analysis, the imperative to save these spectacular species may seem worth the costs including the construction costs to restore nesting habitat, any unavoidable short term damage to sea turtles, and the damage to other more easily replaced and abundant animals and plants that are buried or otherwise harmed in the process (*e.g*., Nelson 1989).

Beach nourishment can be viewed as a tool for restoring lost sea turtle nesting habitat. It has side benefits to other animals and plants, to the coastal economy, and to beachfront property owners. The imperative to restore beaches for sea turtles, however, is not to fight the inevitable movement of barrier islands as sea level rises. Coastal construction setback lines and insurance may handle that issue over an appropriate time frame (Shows 1978, Dean 1989). Instead, it is a sufficiently imposing task simply to replace the losses caused over the last century by capitalizing on the advances in coastal engineering that have occurred in response. Finding enough sand of appropriate quality is an immediate concern. Perhaps more disturbing is the increase in worldwide demand for fuel, as fuel supplies continue to decline. Both the necessary sand and the willpower must be found soon enough if habitat is to be restored before fuel prices increase prohibitively and the opportunity to restore missing sea turtle nesting habitat is lost forever.

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