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Beach Nourishment: A Critical Look

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ABSTRACT

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Beach nourishment has been the main strategy for responding to shoreline recession along the U.S. Atlantic and Gulf coasts for a century. During the last 100 years, $15.7 billion, primarily with federal funds through the U.S. Army Corps of Engineers, has been spent placing 1.2 billion m^3 (1.58 billion yd^3) of sand on the beaches of 475 coastal communities. More than half of this has gone to the states of New Jersey, New York, North Carolina, and Florida. The sand volumes, extent of beach nourished, and costs have all increased over time. Despite the expenditures, the life span of individual nourished beaches has been relatively short in most cases, as evidenced by the frequent repeated replenishment of most sites. Three North Carolina beaches have had sand added more than 20 times, and one of these has been nourished 31 times. Although beach nourishment has been beneficial in terms of recreational value and coastal property protection, the short life spans and the need to continually renourish most beaches, along with the environmental impacts, land subsidence, occurrence of short-term extreme events, and an accelerating rise in sea level, provide a strong rationale for terminating federal expenditures and dependence on short-term beach nourishment and planning for the inevitable long-term necessity of moving back from the shoreline.

ADDITIONAL INDEX WORDS: *Sand replenishment, beach erosion, Army Corps of Engineers.*

INTRODUCTION

Most U.S. coastlines, whether low-relief beaches, dunes, and barrier islands or higher relief bluffs and cliffs, are undergoing recession, albeit at differing rates, which has threatened, damaged, and destroyed both public infrastructure and private development. Causal factors for this increasing recession include a reduction of natural sand supplies, trapping or diversion of sand because of large coastal engineering structures, encroachment of development onto the shoreline, land subsidence, long-term sea-level rise, and short-term extreme events, including hurricanes and severe storms with the simultaneous arrival of large waves and extreme high tides.

However, responses to shoreline erosion or recession are limited. They include armoring of one type or another, beach nourishment, and relocating buildings and infrastructure away from the edge. Along the United States' west coast, armoring has been the dominant approach for nearly a century, primarily concrete seawalls and rock revetments. By 2018, 14% of the entire 1760 km (1100 mi) of California's coast had been armored. However, along the more populated and developed Southern California shoreline (San Diego, Orange, Los Angeles, and Ventura Counties), 38% of the combined four-county shoreline of 373 km (233 mi) had been armored with some type of engineering structure by 2018 (Griggs and Patsch, 2019). Nationwide, Gittman *et al.* (2015) determined that 14% of all U.S. coastlines had been armored.

However, times have changed and policies have evolved in many states, because the multiple impacts of coastal protection structures have been recognized and documented. These impacts include visual effects, reduction of sand supply to the shoreline provided by formerly eroding bluffs or dunes, placement losses or beach area lost by coverage with rock revetments or seawalls, and passive erosion or gradual loss of beach because of sea-level rising against a fixed backshore (Griggs, 2005).

A recent survey of state regulatory responses to sea-level rise and shoreline protection in 22 U.S. coastal states (including Gulf of Mexico states, Alaska, and Hawaii) and 8 states adjacent to the Great Lakes found that 21 of these states have endorsed living shorelines or other soft coastal resiliency approaches in statute, regulation, state policy, or guidance (Moorman, Myers, and Carlin, 2019). Living shorelines have been widely proposed in recent years as more desirable and less impactful than hard armoring (National Geographic, 2023; NOAA Fisheries, 2023; VIMS, 2023), although there is still not clear agreement on what constitutes a living shoreline (Griggs, 2024), and few studies have documented the long-term effectiveness of this approach. There are also significant limitations regarding where such approaches may be

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Figure 1. Shoreline conditions suitable for gray *vs.* green solutions (NOAA Habitat Blueprint, 2024).

effective (Griggs, 2024) and unclear guidance regarding where living shorelines would not be practical or feasible (*e.g.*, high-energy environments; Figure 1).

Although all states continue to allow construction of seawalls and other forms of hard-armoring structures to protect coastal properties in some specific circumstances, all but two of those surveyed by Moorman, Myers, and Carlin (2019) impose regulatory restrictions on such structures. North Carolina has banned construction of new, permanent coastal erosion control structures, with certain narrow exceptions. Of the 30 states surveyed, only 2 states—Alaska and Louisiana—appear to have no statewide regulations or policies applicable to shoreline armoring or living shorelines. However, 28 of the surveyed states impose permitting criteria and restrictions on shoreline armoring structures, with the effect of generally discouraging them except under specified conditions or where no other feasible alternative is available.

BEACH NOURISHMENT OR REPLENISHMENT

In 2000, the Heinz Center for Science, Economics and the Environment reported that 80 to 90% of the sandy beaches along the U.S. Atlantic and Gulf coasts were experiencing erosion, with rates averaging about 0.6 m/y (2 ft/y). Although many factors contribute to shoreline recession, including those listed earlier, sea-level rise is the underlying factor accounting for the long-term and nearly ubiquitous coastal retreat (Leatherman, Zhang, and Douglas, 2000). This land loss has enormous economic and community impacts because coastal areas are some of the most densely developed and heavily populated in the United States and some of the most expensive real estate is beachfront property.

One widely used approach for temporarily forestalling shoreline retreat or beach erosion is to artificially widen or build a protective beach with sand from some offsite source, usually from the offshore continental shelf. This beach nourishment is usually carried out as large-scale projects, where thousands of feet of shoreline are at least temporarily widened with thousands or millions of cubic yards of sand. One of four general approaches for beach replenishment have typically been used (Figure 2; Finkl, Benedet, and Campbell, 2006).

A thorough compilation of beach nourishment along U.S. coastlines was recently published by Elko *et al.* (2021). It built on an earlier assessment by Campbell and Benedet (2006), primarily using detailed information contained on Western Carolina University's (WCU's) website (WCU, 2024), which was originally derived from Duke University's beach nourishment database.

It is important to distinguish between sand that is placed on the beach as a by-product of some coastal construction project or maintenance dredging of a harbor or river channel (usually known as opportunistic nourishment or sand of opportunity), for which a location is needed for disposal or placement, and those projects where sand is imported from offshore or, in some cases, terrestrial sources, with the specific intent to create or widen a beach. With only a few exceptions, the large volumes of sand added to many of California's beaches have been a result of opportunistic nourishment as a by-product of large coastal construction and dredging projects. Flick (1993) summarized the history of beach nourishment in

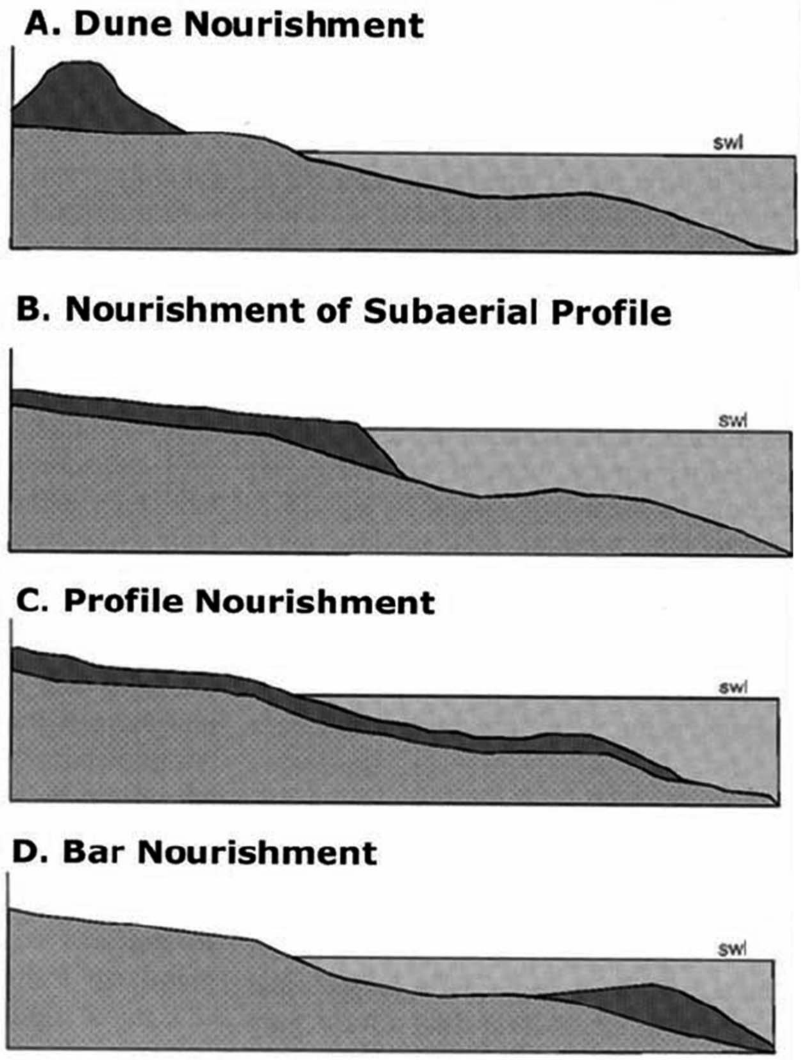

Figure 2. Approaches to beach nourishment depending upon where the sand fill is placed on the shoreline (Finkl, Benedet, and Campbell, 2006).

Southern California and determined that more than 99 million m^3 (130 million yd^3) of sand were added to those beaches between 1930 and 1993 through opportunistic nourishment projects. About half of this amount was divided evenly between the Santa Monica and the Silver Strand littoral cells, where the beaches widened significantly in response to this nourishment. Wiegel (1994) prepared a detailed evaluation of ocean beach nourishment along the entire U.S. Pacific coast.

What are believed to have been the only significant recent beach nourishment projects in California with the sole purpose of widening beaches that were completed by dredging sand offshore were carried out along the San Diego County coast (Regional Beach Sand Project [RBSP] I and II) in 2001 and 2012 (Griggs and Kinsman, 2016). There were two earlier nonopportunistic beach fill projects in Southern California as well. In 1968–69, about one million m^3 (1.3 million yd^3) of offshore sand was placed in the Malaga Cove area adjacent to the Palos Verdes Peninsula to widen that beach. Between 1979 and 1990, nearly 3.8 million m^3 (5 million yd^3) of sand dredged offshore was placed on the Surfside–Sunset Beach area (Wiegel, 1994).

In the first San Diego project (RBSP I), approximately 1.5 million m^3 (2 million yd^3) of sand were dredged from six offshore sites and placed on 12 beaches at a cost of \$17.5 million, or nearly \$14.6/m^3 (\$11/yd^3). Eleven years later, between September and December 2012, RBSP II was completed, which added 1.14 million m^3 (1.5 million yd^3) of sand dredged from three offshore sites to eight San Diego County beaches at a cost of \$28.5 million, or \$25/ m^3 (\$19/yd^3) nearly twice as costly per cubic yard as the earlier project (Griggs and Kinsman, 2016).

About 174 million m^3 (229 million yd^3) of sand has been dredged from California's 16 coastal harbors since their construction through 2020 and placed on adjacent beaches

(Patsch and Griggs, 2021). However, this has not been the case along the Atlantic and Gulf coasts, where most sand added to the beaches of these areas has been dredged from the offshore continental shelf expressly to widen or nourish beaches.

Beach nourishment has been employed for a century along the low-relief, typically barrier island-backed sandy shorelines of the Atlantic and Gulf coasts of the United States. The earliest effort to artificially nourish a beach began with a 1923 Coney Island, New York, project (Elko, et al., 2021). In the late 19th century, Coney Island was America's biggest and most popular shoreline resort and amusement park destination and had some of the largest and most luxurious hotels in the nation. In its earliest years, the beach here was privately owned, but in 1923, it officially became a public beach and was expanded. The New York City Department of Parks and Recreation pumped sand onto the shoreline from offshore to expand the beach area. This was the first of what was to grow to thousands of beach nourishment projects that continue a century later.

Extent and Magnitude of U.S. Beach Nourishment

Two extensive databases summarize U.S. beach nourishment projects, one developed and maintained by WCU (2024) and the second by the American Shore and Beach Preservation Association (ASBPA, 2024). These are searchable by state and include individual locations, dates, volumes, and purposes. Considerable effort has been extended to collect these data and develop the records, although there are some significant gaps in the records because of incomplete recording by the Army Corps of Engineers, which carries out most of these projects.

However, the data presented in these two databases rarely agree completely. For example, the WCU site reports 2482 individual nourishment episodes, whereas the ASBPA site reports 3633 episodes. WCU lists a total volume of 1,200,068,128 million m^3 (1,579,037,010 yd^3), whereas ASBPA lists 1,276,389,376 m^3 (1,679,459,705 yd^3). Although ASBPA lists a known total cost of \$8.8 billion, WCU lists a total cost of \$10.3 billion but a 2022 adjusted cost of \$15.7 billion. There are several possible explanations for these differences. Records for individual projects may not be up to date, and sand volumes may be unavailable or presented as either amounts actually dredged or bathymetric or topographic changes in areas where sand was removed or deposited. In some cases, a project was presented as carried out in the ASBPA database, but a search by WCU staff could not find any record of the project being completed. The number of nourishment episodes may also vary; WCU might report a multidecadal effort as one project, whereas the Army Corps of Engineers may nourish the beach multiple times. In addition, as discussed subsequently, the Army Corps of Engineers records are not always complete, and those numbers are the primary information source for both the WCU and the ASBPA databases.

Although there are some significant differences in the two databases, the major conclusion is that large volumes of sand have been placed on hundreds of Atlantic and Gulf coast beaches over the past century at great expense. Evidence indicates that the ASBPA database was originally extracted from the WCU site (which was developed from an earlier Duke University history), so in this analysis, the WCU data are used for consistency.

More than 1.2 billion m^3 (1.58 billion yd^3) of sand has nourished the beaches of 475 U.S. communities since 1923, at a 2022 adjusted cost of \$15.7 billion. Most funding has come from the federal government through appropriations to the Army Corps of Engineers. Although some of this sand has come from entrance channel dredging and therefore is opportunistic sand, most has been dredged from offshore with the specific goal of nourishing beaches.

This is a difficult volume of sand to visualize, but it is enough sand to build a beach 50m (150 ft) wide, 4m (12 ft) deep, and about 8000 km (5000 mi) long, or a beach extending all the way down the Atlantic seaboard from Maine; around the southern tip of Florida; west across Alabama, Mississippi, Louisiana, and the entire state of Texas; and then along the entire coasts of Washington, Oregon, and California (distances were obtained from CRS, 2006; were determined from large-scale nautical charts; and do not include tidal inlets). This volume of sand would fill 158 million 10-yd^3 dump trucks. In short, 1.2 billion m^3 (1.58 billion yd^3) is a massive amount of sand. The annual volumes of sand placed, the length of shoreline nourished, and the costs have all gradually increased over time, at least until the last several years (Figure 3; WCU, 2024; Elko *et al.*, 2021).

Six states account for more than 83% of the total volume of sand placed on U.S. beaches: California, Florida, New Jersey, North Carolina, New York, and Louisiana (Elko *et al.*, 2021). However, as discussed earlier, nearly all California yardage is from opportunistic sand, rather than sand dredged offshore for beach nourishment.

Most of this sand (1453 projects and 54% of the volume) has gone to the beaches of Florida, North Carolina, New York, and New Jersey, which have benefited from approximately 643 million m^3 (846 million yd^3 of sand since the 1930s. The cost for these four states has been \$9.523 billion, or 61% of the national costs, most of this funded by the federal government (WCU, 2024).

Florida has been the largest recipient of federal beach nourishment funding, with 27.4% of the national projects, 22.2% of the total sand volume, and 25% of the adjusted costs. Palm Beach County alone, as one example, has benefited from 84 nourishment projects from a mixture of offshore dredging and Lake Worth inlet maintenance. It is not clear from the WCU database where the sediment from Lake Worth inlet dredging goes; presumably, it is onto local beaches. The inlet has been dredged 18 times, with 5.7 million m^3 (7.5 million yd^3) removed at a cost of \$46 million. Between the first dredging in 1944 and 1985, there is no funding source or justification listed (WCU, 2024). In 1987–98, the federal government is listed as the funding source and the justification is navigation.

The beaches of Palm Beach County (as distinct from Lake Worth inlet dredging) have been nourished 59 times and have benefited from 27.4 million m^3 (36.1 million yd^3) of sand at a 2022 adjusted cost of \$254 million. However, these are both minimums, because six nourishment events have no volumes listed, 16 events that have no costs listed, and the Lake

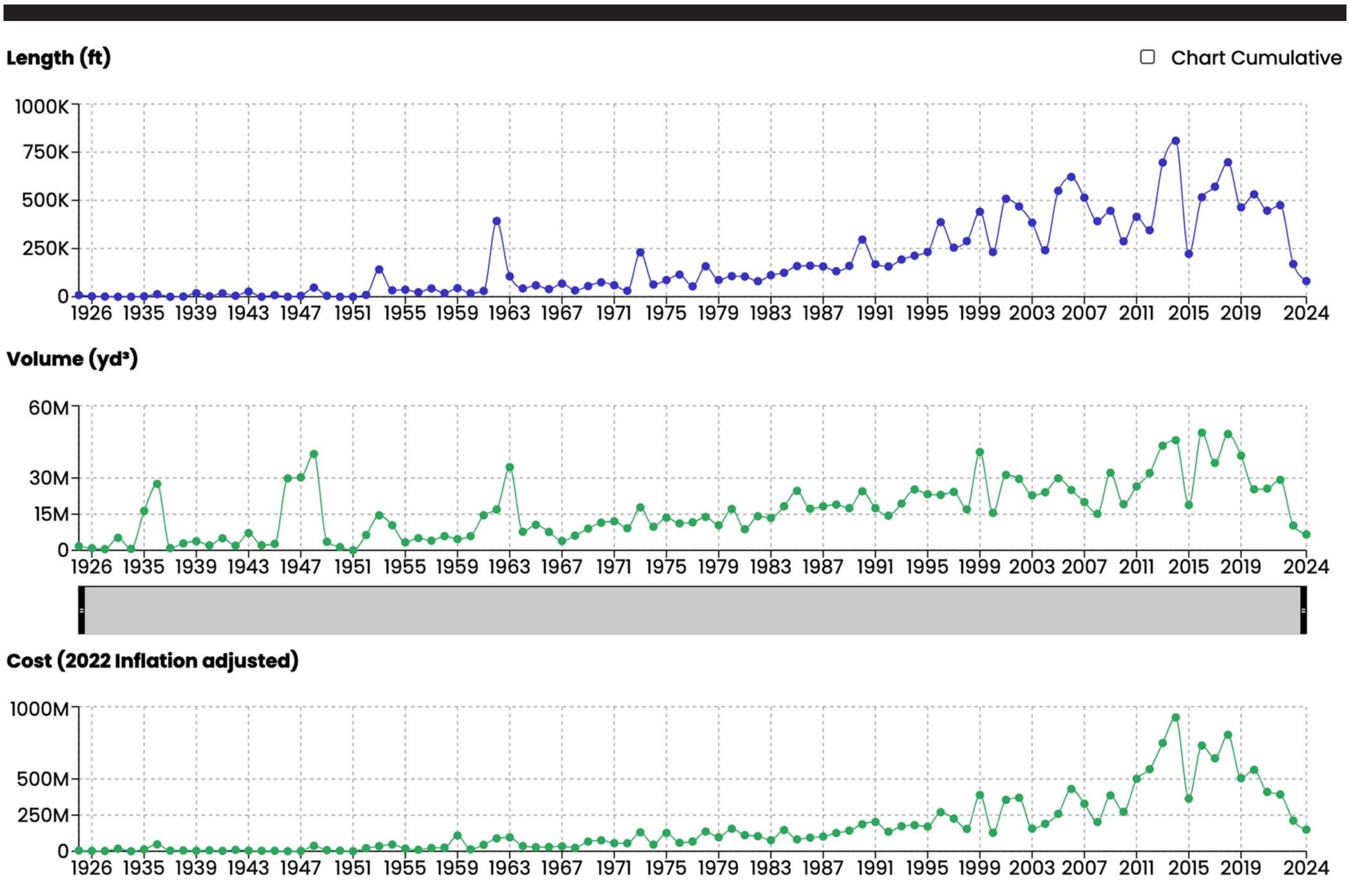

Figure 3. Progressive increases in length of shorelines nourished, volumes of sand, and costs (WCU, 2024).

Worth dredging episodes are not included in this total (WCU, 2024). The justification for these beach projects is listed as either shore protection or unknown, but it is safe to assume these were likely all for shore protection. The Palm Beach County shoreline is backed by a mixture of large homes, condominium or townhome developments, hotels, a mobile home park, and a few golf courses (Figure 4), essentially all private development.

Benefits of Beach Nourishment

Beach nourishment clearly has important benefits. Widely cited examples are the three projects in 1978, 1979, and 1980 that delivered approximately 5,069,000 m^3 (6,670,000 yd^3) of sand to Miami's beaches at a cost of $119 million (WCU, 2024), which brought back the visitors and hence the economy. White coral sand was pumped from deposits a few miles offshore, and Miami Beach was widened by approximately 60m (200 ft along the nearly 6 km (10-mile-long barrier island shoreline. This beach nourishment project has often been cited as the most successful beach restoration in the United States because of its longevity and positive economic impact (Houston, 2013).

However, these projects were not a permanent solution for Miami Beach. Between 1982 and 2001, following that large nourishment project, more than 4.6 million m^3 (6 million yd^3) of additional sand was pumped from offshore onto Miami Beach at a cost of $122.2 million (WCU, 2024). This cost is slightly more than the original projects but is a minimum, because six of the subsequent projects have no cost listed in the WCU database. The ASBPA site lists 38 nourishment events for Miami Beach between 1980 and 2023, with a total volume of 14,749,245 m^3 (19,406,902 yd^3) and a total cost of $128.3 million.

Houston (1995, 1996, 2002, 2008, 2013, 2018) has written extensively on the economic value of beaches, making a strong case that travel and tourism constitute America's largest employer and that beaches are the nation's leading tourist destination. He also cites extensive economic data to argue for the value of nourishing or renourishing beaches where they have been eroded or narrowed to support this economic engine. Tourism generated by U.S. beaches is a multibillion-dollar industry, with an estimated income of $285 billion annually to the nation's economy (in 2017 U.S. dollars; Houston, 2018). The economic benefits of these projects are clear, but nourishment is also facing increasing challenges from costly maintenance because of the short life span of most projects, repeated need to renourish, increasing threats from rising sea levels and subsiding shorelines, increasing hurricane and storm intensity, biological impacts of the offshore areas where sand is dredged, and beach impacts where the sand is discharged.

Figure 4. Section of Palm Beach County shoreline (Google Earth, 2024).

Life Span and Effectiveness of Nourished Beaches

More than $15 billion, mostly federal dollars, have been spent moving sand to the shoreline for both recreational and shoreline protection benefits. Still, whether in New Jersey, New York, North Carolina, Florida, or California, the life span of the sand added artificially to these beaches in many cases has been relatively short and in some instances has been less than a year.

During the 2001 RBSP I nourishment project in San Diego County, California, about 1.5 million m^3 (2 million yd^3) of offshore sand was placed on 12 county beaches. Some overall conclusions can be drawn from the 4 years of published beach surveys in the nourished areas (Coastal Frontiers, 2005). The performance of individual beach fills varied considerably. At some sites, the gains in width were short lived, at least on the subaerial beach (Griggs and Kinsman, 2016). Nearly all sand added to the beaches tended to move both offshore and down coast with the arrival of more energetic winter waves.

A detailed study of the RBSP I Torrey Pines State Beach fill project was carried out as part of postnourishment monitoring (Seymour *et al.*, 2005). This back beach fill was about 500m (1600 ft) long and included about 158,000 m^3 (208,000 yd^3) of sand. The fill was completed near the end of April 2001 (Figure 5). Wave conditions during the summer and fall were mild, with significant wave heights generally less than 3 ft. At noon on 22 November 2001, significant wave heights reached nearly 10 ft and remained in the range of 9 to about 10 ft. for 7 hours. The fill was overtopped and began to erode quickly. By the next morning, the fill had been almost completely eroded to the riprap at the back of the beach (Seymour *et al.*, 2005). The fill was stable for approximately 7 months of low-wave-energy conditions but was removed from the subaerial beach within several days when the first large waves of the winter arrived.

Salisbury Beach, an oceanfront community in northern Massachusetts, recently spent $600,000 to import about 8,400 m^3 (11,000 yd^3) of sand to build a protective dune in front of the community's homes. The project was completed on 7 March 2024, just before a nor'easter hit the coast, which removed about half of the sand within 3 days. The president of the organization who had promoted the project stated, "The dunes were sacrificial. They sacrificed themselves to protect the properties. Water didn't go into people's living rooms, destroy houses, destroy decks, patios, and so on. So the dunes worked." In the same interview, the individual—a real estate agent who rents coastal homes—stated, "It was devastating. Water went from the ocean into people's living rooms and kitchens. Patios were destroyed. And at least one home was deemed uninhabitable" (Salam, 2024, p. 1).

Some perspective on the life spans of individual nourishment projects can be derived from the frequency of renourishment efforts, or the number of times individual beaches have been renourished. In one state's examples, 10 North Carolina beaches have been nourished at least 10 times each. Three of these have been nourished more than 20 times, and one, Carolina Beach, had sand added 31 times (Table 1). A logical conclusion from these data is that nourishment is rarely a one-time process. Most beaches have required repeated and often frequent renourishment, which is a process that may likely continue for the long term, until this is no longer deemed practical and effective, or until funding is no longer appropriated or approved.

It is clear from the preceding examples that beach nourishment cannot be seen as a permanent or even long-term solution to beach or bluff erosion. It simply buys a little more time at great public expense.

Overall, the practice of beach nourishment is widespread but remains controversial. Shorefront cities and development have come to rely upon continuing federally funded projects to increase, restore, and maintain beach width and property values. Despite maintaining the beach in many locations for storm protection of property, as well as for recreation and beach-dependent economic activities, renourishment projects are costly and short-term interventions. These are paid for by taxpayer money and often maintain high real estate values for those who live by the beach, which can be considered a form of subsidy to the wealthy (Figure 4; U.S. Commission on Ocean Policy, 2004).

Biological Impacts of Beach Nourishment

Traditional approaches to beach nourishment that merely add sand have had limitations in effectiveness. Environmental

Figure 5. Approximate extent of fill on the back beach at Torrey Pines State Beach in 2001 during RBSP I (Seymour *et al.*, 2005).

impacts and limited success for beach replenishment may occur when one or more of the following factors is lacking: (1) a realistic assessment of potential borrow area sand volume, (2) compatibility of added sand to the beach being nourished, (3) construction costs, (4) vulnerable geomorphic elements of the coastal zone, and (5) environmental impacts.

The ecological consequences of beach nourishment or replenishment have often been shown to be significant (Woodbridge, Henter, and Kohn, 2016). Adding sand artificially to beaches can bury shallow reefs and degrade other beach habitats, depress nesting of sea turtles, and reduce the abundance of invertebrate prey for shorebirds, surf fish, and crabs (Peterson and Bishop, 2005). Although agency-required monitoring of these projects has gone on for decades and at considerable cost, significant uncertainty remains about the biological impacts of beach nourishment. Peterson and Bishop (2005) reviewed 46 beach monitoring studies and concluded that (1) just 11% of the reports controlled for both natural and spatial variation in their analyses, (2) 56% reached conclusions that were not adequately supported, and (3) 49% failed to meet publication standards for citation and synthesis of related work. Overall, pre- and postnourishment monitoring has often been inadequate to resolve questions of environmental impacts.

Table 1. *Nourishment data for the 10 North Carolina beaches that have been nourished more than 10 times.*

Beach	Nourishment Episodes	Total Cost
Carolina Beach	31	$103 million
Topsail Beach	10	$42 million
Wrightsville Beach	26	$94 million
Holden Beach	27	$46 million
Ocean Isle	16	$48 million
Bald Head Island	15	$106 million
North Topsail	19	$50 million
Emerald Isle Point	13	$2.5 million
Fort Mason	11	$44.5 million
Pea Island	16	$36.5 million

Costs have been adjusted to 2022 U.S. dollars (WCU, 2024).

Challenges to Sustainable Beach Nourishment

To be cost-effective and last for an extended period, beach nourishment in most locations needs to be combined with sediment retention techniques, whether groins or some other effort to hold the sand in place so that it survives for a longer period and reduces or avoids frequent and costly replenishment. This requires understanding the historic causes of beach erosion, either episodic or chronic, and the long-term littoral drift rates and directions (Capobianco *et al.*, 2002; Hanley *et al.*, 2014).

In some cases, it is clear that the historic or natural beach width hasn't changed significantly but that arguments were made and political support was developed for artificially widening the beach, whether for property protection or for increased recreational area (Griggs and Kinsman, 2016). However, every stretch of shoreline has some equilibrium beach width that is a function primarily of (1) the wave climate, (2) coastline configuration, (3) presence of natural barriers to littoral drift, and (4) sediment supply. Still, there is no reason artificially added sand should sustain a beach wider or larger than its natural equilibrium for an extended period.

Continuing and accelerating sea-level rise, larger and more intense hurricanes, and increased wave energy, as well as regional subsidence, will all affect nourished beaches even more severely in the future. Although the Army Corps of Engineers, as well as many local beach communities and coastal organizations, continue to put forward beach replenishment as a soft solution to coastal erosion or beach loss, other lines of evidence indicate that beach replenishment (alone) may not be a sustainable strategy in the long term to mitigate the impacts of climate change. Parkinson and Ogurcak (2018) report that recent studies that concluded nourishment of oceanic beaches is a viable strategy to mitigate climate change (Houston, 2017) were generally too limited in scope to accurately evaluate beach nourishment, because each of these studies omitted one or more of the following: (1) a realistic assessment of the volume of potential sand sources, (2) compatibility of sand sources with native beach material, (3) construction costs, (4) all vulnerable geomorphic elements of the coastal zone, and (5) environmental impacts. When all of these elements are considered, Parkinson and Ogurcak (2018) concluded that the results are markedly different from those reported by Houston (2017). They provide multiple lines of evidence that beach nourishment projects are not a sustainable approach to protect ocean beaches of the Florida Panhandle or likely most of the world's developed coastlines at risk of rising sea levels and other effects of climate change. Although they believe that beach nourishment may likely continue for the next several decades, they state that this must be considered an interim approach while a long-term adaptive management strategy is formulated and implemented that incorporates managed withdrawal from the shoreline (Parkinson and Ogurcak, 2018). In California, model projections indicate that beach replenishment will only marginally delay the long-term inevitable loss of Southern California beaches because of sea-level rise (Vitousek, Barnard, and Limber, 2017).

Nearly 30 years ago, in 1995, the National Research Council produced a thorough report, Beach Nourishment and Protection, that evaluated the engineering, environmental, economic, and public policy aspects of beach nourishment "to provide an improved technological basis for judging the use of beach nourishment and protection technology in shoreline stabilization, erosion control, recreational beach creation, dredged material placement, construction of coastal storm barriers, and protection of natural resources." However, at that time, sea-level rise was not the concern that it is today, and this issue was only briefly discussed in two paragraphs quoted as follows: "The overall effect of a gradual relative sea-level rise at the present rate will not be detectable in the rate of beach loss" (p. 146) and "Sea-level change, however, is just one of many factors impacting beach behavior. Its magnitude and relative importance are difficult to ascertain because changes are masked by more dramatic near-term fluctuations caused by other physical forces. Relative sea-level rise will probably remain a minor factor affecting replenished beach durability during the next several decades" (p. 146). In addition, measurements of absolute or global sea-level rise using satellite altimetry had just been initiated in 1993. Several decades have passed since this report was released, and continuing sea-level rise has become a more significant issue, partly because of its well-documented acceleration (Boon *et al.*, 2018; Nerem *et al.*, 2018).

Table 2. *Sea-level rise rates from selected Atlantic coast National Oceanic and Atmospheric Administration tide gauges.*

Tide Gauge Location	Average Sea-Level Rise Rate (mm/y)
Cape May, New Jersey	4.99
Atlantic City, New Jersey	4.21
Ocean City, Maryland	5.15
Sewell's Point, Virginia	4.79
Lewisetta, Virginia	5.87
Dahlgren, Virginia	5.63
Wachapreague, Virginia	5.63
Oregon Inlet, North Carolina	5.86
Duck, North Carolina	4.88
Port Canaveral, Florida	6.62
Lake Worth Pier, Florida	4.88

However, the local sea-level rise rate is affected by vertical land motion. Projections along U.S. coastlines of future sea-level rise increase the probability of more destructive flooding and inundation in many major cities. However, these impacts may be exacerbated by coastal subsidence, a process that is often underrepresented in coastal management policies and long-term urban planning (Ohenhen *et al.*, 2024). Not only will local subsidence affect low-lying coastal areas through more frequent and a greater extent of flooding, but this will also affect and shorten the life of beach nourishment efforts. Tide gauge records from several Atlantic coast locations in five states have recorded local sea-level rise rates well above the 30-year mean global sea-level rise rate of 3.1 mm/y. from satellite altimetry (Table 2; NOAA Laboratory for Satellite Altimetry, 2024), which provide evidence for regional coastal subsidence, as determined by Ohenhen *et al.* (2024).

DISCUSSION AND CONCLUSIONS

Beach nourishment has been the primary response to shoreline erosion and flooding along the Atlantic and Gulf coasts for a century. Over this period, about 1.2 billion m^3 (1.58 billion yd^3) of sand have been placed on the beaches of 475 U.S. communities, with most of this volume coming from the offshore continental shelf and a lesser amount from opportunistic sources such as the dredging of harbors or river channels. The total adjusted cost has reached $15.7 billion, with most money coming from federal funding through the Army Corps of Engineers. Although some of this funding has gone to dredging harbors and channels, the justification for most nourishment projects has been for recreation and shore protection, typically to protect private development.

More than half of this sand (54% of the total volume) has gone to the beaches of Florida, North Carolina, New York, and New Jersey, which have received approximately 643 million m^3 (846 million yd^3) of sand since the 1930s. The cost for these four states has reached $9.5 billion, or 61% of nationwide costs. The sand volumes, costs, and extent of shorelines nourished have all increased over time. Despite these increasing expenditures, the life span of individual nourishment projects has been relatively short. Databases maintained by both WCU and ASBPA indicate frequent repeat nourishment projects in many locations.

Using North Carolina as an example, 10 beaches at have been nourished at least 10 times. Three of these have been nourished more than 20 times, and one, Carolina Beach, has had sand added 31 times. It is clear from these examples that beach nourishment cannot be seen as a permanent or even long-term solution to beach or bluff erosion but simply buys a little more time at great public expense.

Nearly all beaches have some equilibrium width or size that is a function primarily of (1) the wave climate, (2) coastline configuration, (3) presence of natural barriers to littoral drift, and (4) sediment supply. However, there is no reason sand artificially added to a beach in natural equilibrium should remain for an extended period. Retention structures could extend the lifetime of nourished beaches but are rarely used along the Atlantic or Gulf coasts. Without question, there are significant benefits to beach nourishment, but these come at significant and recurring costs paid for primarily by the federal government. There are also ecological impacts associated with both dredging up seafloor sand offshore and discharging the sand onto the shoreline.

Although a case has been made that beach nourishment is a sustainable strategy for mitigating the effects of ongoing and accelerating sea-level rise, the study that produced this conclusion has been criticized for being too limited in scope and for omitting many key considerations. Land subsidence is also a long-term process along the U.S. Atlantic coast, which along with the increasing severity and size of hurricanes, will also shorten the life span of beach nourishment projects. Twenty-four years ago, the Heinz Center (2000) concluded that of the 10 Atlantic and Gulf coast counties analyzed, only 1 county could justify the cost of beach nourishment based on expected erosion damage over the next 60 years.

After a century of beach nourishment with increasing expenditures and volumes of sand being pumped from offshore onto beaches, as well as a clearer understand of the challenges posed by an accelerating rate of sea-level rise, shoreline subsidence, and short-term extreme events such as nor'easters and hurricanes, it is time to face reality. We cannot continue to nourish our way out of sea-level rise and recurring storm damage at increasing public expense but instead need to seriously plan now for a longer-term future for the shoreline and the inevitable necessity of moving inland.

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