Inlet-adjacent beach and shoreline variability at decadal scales

By

Teagan Duenkel[1] and Tiffany Roberts Briggs, Ph.D.[1]
1) Dept. of Geosciences, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431
Tduenkel2020@fau.edu

ABSTRACT

Beaches provide storm protection and economic benefit for coastal communities and also host important habitats for keystone species, especially in the state of Florida. However, sea level rise, coastal construction, and intensifying storms are resulting in coastal erosion, which often requires informed mitigation and management strategies. This study aims to explore decadal-scale trends in morphology change and shoreline variability of inlet-adjacent beaches in Jupiter, Florida. Data from three locations over a period of three decades were analyzed to determine volumetric and contour changes above the shoreline (0 m elevation) and across the entire profile. The largest variability in decadal morphology change was measured at beaches closest to Jupiter Inlet. Substantial shoreline and beach changes were also associated with periods of higher storm activity. Variability in storm events, nourishment trends, and longshore sediment transport also influenced decadal morphologic change. To best adapt to coastal change and develop comprehensive beach-inlet management plans, it is imperative to understand past trends of shoreline variability and beach-nearshore erosion and accretion patterns. Results of this study demonstrate an approach to elucidate decadal patterns in morphology changes and drivers of change.

KEYWORDS: Beneficial Use of Dredged Materials (BUDM), inlet, beach elevation contour, nourishment, storm events.

Manuscript submitted 27 April 2023, revised and accepted 22 November 2023.

Coastal change can result from a variety of causes, including storm events, changes in wind and waves, beach nourishment activities, human development, and other morphological influences. In recent years, coastal erosion is of increasing concern due to the vulnerability of densely developed coastlines. Rising eustatic sea levels coupled with severe storm events are intensifying the rate of coastal erosion, creating a greater need to understand the relationship between coastal morphology and human interactions.

Storm impacts play a significant role in rapid morphological change to the coastline. Shoreline changes depend on the prior beach dimensions (including width and dune elevation) and various storm parameters such as size, intensity, and speed (Briggs *et al.* 2021). Often, beaches with narrower widths will experience more significant erosion after a storm event. Itzkin *et al.* (2021) documented that increasing the beach width reduces inundation and overwash by diffusing wave impacts. They also found that nourishment and sand fencing afforded the most protection during a storm event by reducing the wave exposure time at the dunes. After a storm event, beaches will often undergo a natural recovery period in response to calmer weather and sea conditions. However, if consecutive storms occur, the recovery period can be longer than the return period of the next storm and increase damages to a beach system. Consecutive storms with small return periods induce average erosion volumes as significant as a single storm with a much larger return period (Karunarathna *et al.* 2014).

Tidal inlets are also sources of coastal erosion at adjacent shorelines. Tidal inlets are channels separating barrier islands leading from the ocean to a bay. Depending on the tidal cycle, sand can be deposited seaward or landward by ebb and flood currents, respectively. Numerous studies have shown that both natural and structured tidal inlets interrupt the natural longshore drift/sediment transport, changing the morphology of the adjacent beach and leading to erosion (Bruun 1996, FitzGerald 1996, Galgano 2009, and Adams *et al.* 2016). Adams *et al.* (2016) documented ebb-tidal deltas disrupting wave patterns and impacting adjacent beach accretion patterns. Structured inlets are often subject to dredging events and annual maintenance to maintain the navigational waterway for boats and commerce. Beneficial Use of Dredge Material (BUDM) is becoming a common practice of reusing dredged material for productive methods, such as nourishment of a nearby area, rather than placing the sediment at an offshore disposal site where it is lost from the littoral system. According to the U.S. Army Corps of Engineers (2022), 30%-40% of dredged material is currently used for beneficial uses. Reusing dredged material conserves primary resources and reduces the disturbance to marine fauna and sediment patterns in offshore borrow areas.

Beach nourishment is a common erosion mitigation technique, placing sediment on a beach to replenish sand that has been lost from the littoral system using borrow sources such as inlets, offshore deposits, and upland mines. Sometimes sand is placed updrift of an eroded area, with the expectation that the beach system will progress towards equilibration by moving placed sediment downdrift (Cheng *et al.* 2016). After a nourishment event, beach profile monitoring is a crucial step in understanding the effectiveness of the treatment as well as supporting best management practices for future nourishment events, including for downdrift locations.

The objective of this study is to quantify annual and decadal morphologic variability of three inlet-adjacent beach profiles within the same geographical region in northern Palm Beach County. Volumetric and contour changes above the shoreline and across the entire profile are quantified and compared to

Figure 1. Aerial view of Jupiter Inlet; R13 is located south of the inlet. Copyright © Jupiter Florida Loxahatchee River photo, D. Ramey Logan.jpg 2014.

known storm and nourishment/dredge events to explore primary drivers of change. Coastal morphology variability greatly impacts coastline-dependent industries, such as tourism, agriculture, and maritime transport, as well as local flora and fauna. Therefore, understanding multi-scale patterns should help improve prediction of sediment transport patterns and better protect coastal environments.

STUDY AREA

Palm Beach County

Palm Beach County is located on the east coast of South Florida and includes larger expanses of critically eroded shoreline in comparison to non-critically eroded shoreline (FDEP 2021). The Outcrops of the Anastasia Formation, consisting of coquinoid limestone with quartz sand and coarse-grained shells, are exposed where the Formation elevation is above mean sea level or where wave energy removes unconsolidated sediment. The dominant direction for longshore sediment transport in the region is to the south. Sediment characteristics for Palm Beach County are generally light gray, moderately sorted, medium sand (Briggs *et al.* 2021). The area consists of both nourished and non-nourished beaches, with managed beaches using borrow sources that include offshore deposits, inlets, and/or upland mines. In northern Palm Beach County, material is often sourced as BUDM from the Jupiter Inlet or from an offshore source. The Jupiter Inlet intersects the Atlantic Ocean, the Intracoastal Canal, and the Loxahatchee River (Figure 1). Storm impacts in southeast Florida are common, and numerous major hurricanes — including Hurricanes Andrew (1992), Wilma (2005), Sandy (2012), and Irma (2017) — have impacted Florida's east coast over the past several decades.

METHODOLOGY

Three locations aligning with the Florida Department of Environmental Protection's (FDEP) R-monuments were analyzed in this study (R13, R17, and R21). FDEP R-monuments are spaced 300 m apart along Florida's shoreline and used for standardized surveying. R13 is directly south of the Jupiter Inlet; the ebb-tidal delta attachment point to the longshore bar and trough system varies between R17 and R19; and R21 was selected as the southernmost site for the study area (Figure 2). The FDEP obtains beach profile surveys on a nearly annual basis. For this study, time-series survey data were obtained from the FDEP database for the past three decades for analysis. Subsequently, all original government Microsoft Outlook Profile (PRF) files were converted to cross-sectional profiles and plotted in Excel. Data were then input to the Beach Morphology Analysis Package (BMAP) and analyzed for changes in the volume of sand (m^3) above the shoreline and across the entire profile and for contour changes (m) at the shoreline. To assess decadal trends at each location, a total of 177 cross-sectional profiles were evaluated for volume and contour changes above the shoreline (approximated at the 0-m elevation NAVD88) and across the entire profile to the approximate depth of closure. Average of change between surveys within each decade was performed to illustrate general decadal trends.

Information on storm events impacting the study area was obtained from the National Oceanographic and Atmospheric Administration (NOAA 2020). Records on nourishment events impacting the study area were obtained through the American Shore & Beach Preservation Association's (ASBPA 2009-2022) Beach Nourishment Database, and records on dredging events were obtained from the Jupiter Inlet District's Sand Trap Dredging History data resource (https://www.jupiterinletdistrict.org/sand-trap-dredging-history).

RESULTS

Morphological trends

During the 30-year time period, all study locations experienced an overall decrease in beach width, i.e., the distance

Table 1

Impactful storm events in South Florida throughout the study period.

Date	Category	Name
24 Aug. 1992	5	Andrew
16 Oct. 1999	2	Irene
13 Aug. 2004	4	Charley
5 Sept. 2004	2	Frances
25 Sept. 2004	3	Jeanne
25 Aug. 2005	1	Katrina
24 Oct. 2005	3	Wilma
18 Aug. 2008	T.S.	Fay
26 Aug. 2012	T.S.	Isaac
26 Oct. 2012	2	Sandy
6 June 2013	T.S.	Andrea
6 Oct. 2016	2	Matthew
10 Sept. 2017	4	Irma
6 Sept. 2019	2	Dorian

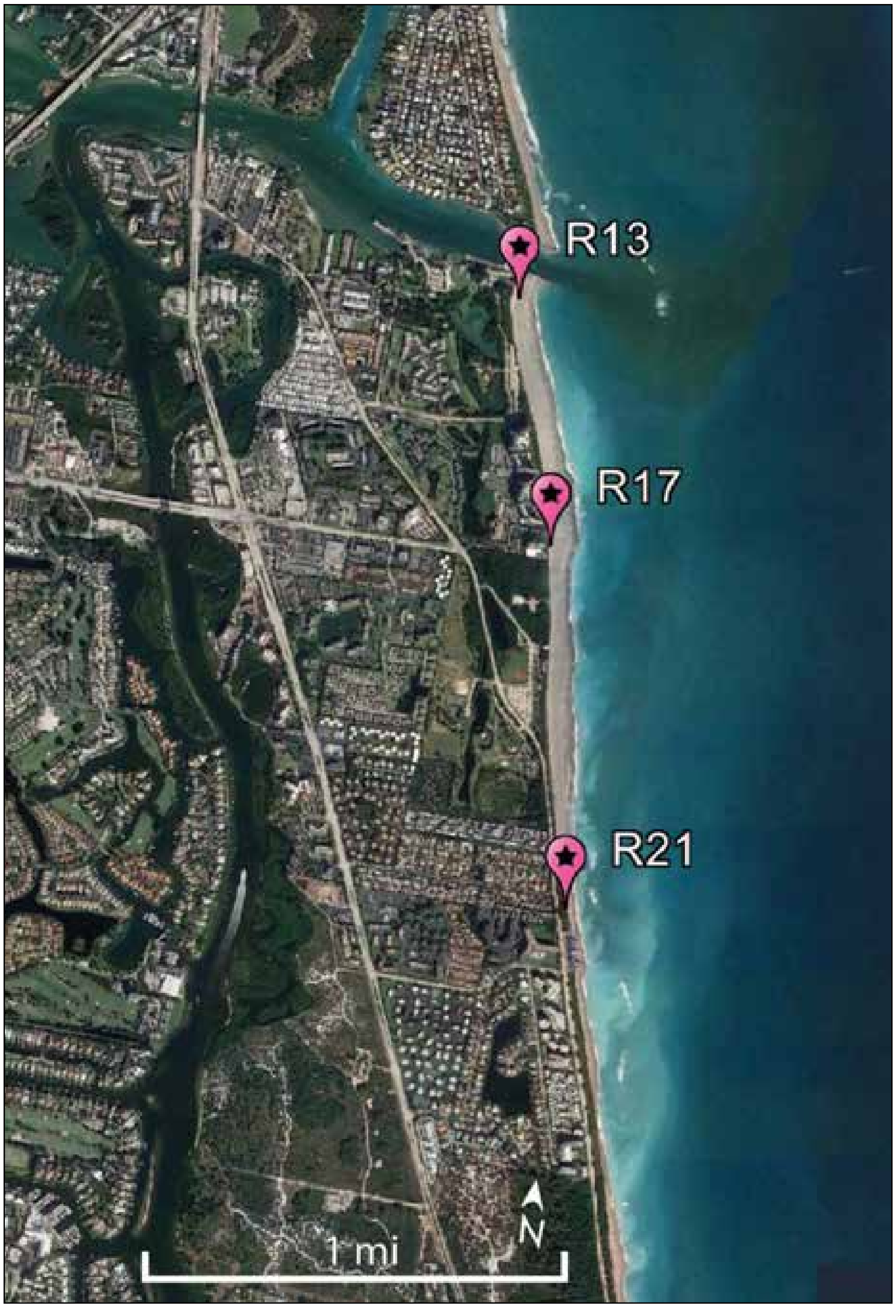

Figure 2. Geographic locations of beach profiles at DNR R-monument sites.

from the dune to the Mean High Water (MHW) position. The profile at R13 exhibited the most variability in beach width and bathymetry (Figure 3). In 1995, a large depression was measured that was subsequently filled in. Bathymetric changes were measured over time to 10 m of water depth (and likely beyond). It is unclear whether a sandbar formed in 2008 at R17 or if a nearshore ridge was the ebb-tidal attachment at this time (known to migrate between R17 and R19). However, the ridge subsequently migrated offshore in 2012 and then remained relatively stable (Figure 4). Aerial imagery (Google Earth) shows the attachment point coinciding with R17 in 2011 and then migrating south thereafter. Beach width at R17 was significantly wider in August 2005 and August 2006 (Figure 4). Throughout the study period, beach erosion and accretion with a migratory sandbar was measured at R21. The beach was widest in October 2010 (Figure 5). R13 exhibited the highest degree of variability in volume change. The most substantial volume change at R13 took place between July 2004 and August 2005, resulting in a loss of just over 1,000 m^3 (Figure 6). However, the most significant shoreline volume change occurred between July 2012 and December 2012, resulting in a ~450 m^3 loss. The total volume change at R17 followed a similar pattern to shoreline volume change (Figure 7). The largest shoreline changes were of smaller magnitude and occurred a few years prior to the largest overall changes. The largest shoreline change occurred between October 2002 and September 2003 (~400 m^3 loss), while the largest total change occurred between August 2005 and August 2006 (~800 m^3 loss). Overall, less shoreline and total volume change was measured at R21 as compared to the other sites.

Storms impacts

Fourteen storm events were reported by NOAA as having an impactful effect on South Florida during the study period (Table 1). Some of these storm events had lasting impacts on the beaches. For example, R13 (directly south of the inlet) had altered bathymetry from the intense and unprecedented 2004-2005 hurricane season and has not yet fully recovered to the pre-storm state. A shift in the pre- and post- 2004-2005 depth of closure at R13 shows a post-nearshore morphology approximately 1 m deeper prior to these storms (Figure 3). The deepest bathymetry measured within the nearshore also supervened the 2004-2005 hurricane season (Figures 3 and 4). From July 2004 to August 2005 (Figures 3 and 6), profiles exhibit extensive nearshore and offshore erosion, attributed to Hurricane Jeanne in September of 2004. Significant erosion amounting to ~570 m^3 at R13 between August 2005 and August 2006 is attributed to Hurricane Katrina in late August 2005 and Hurricane Wilma in October 2005 (Figures 3 and 6). A similar pattern of nearshore and offshore loss is evident at R17 during the same time period

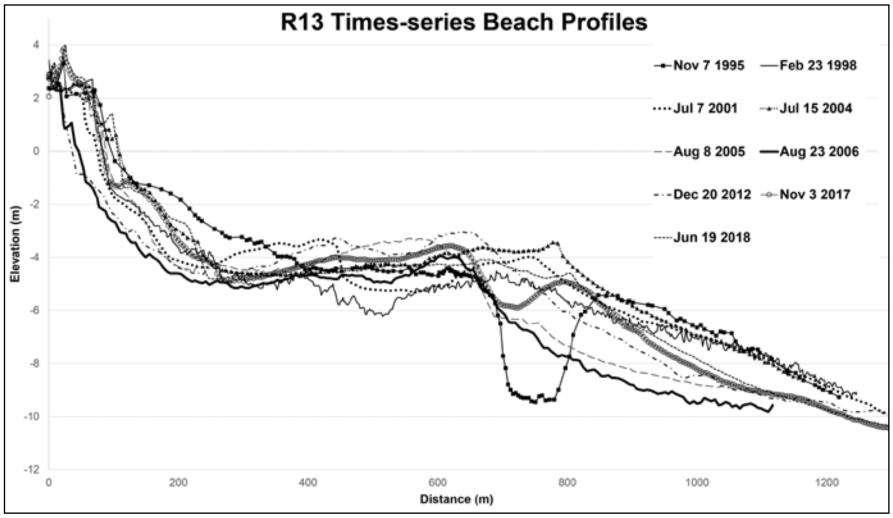

Figure 3. R13 time-series beach profiles across the study period.

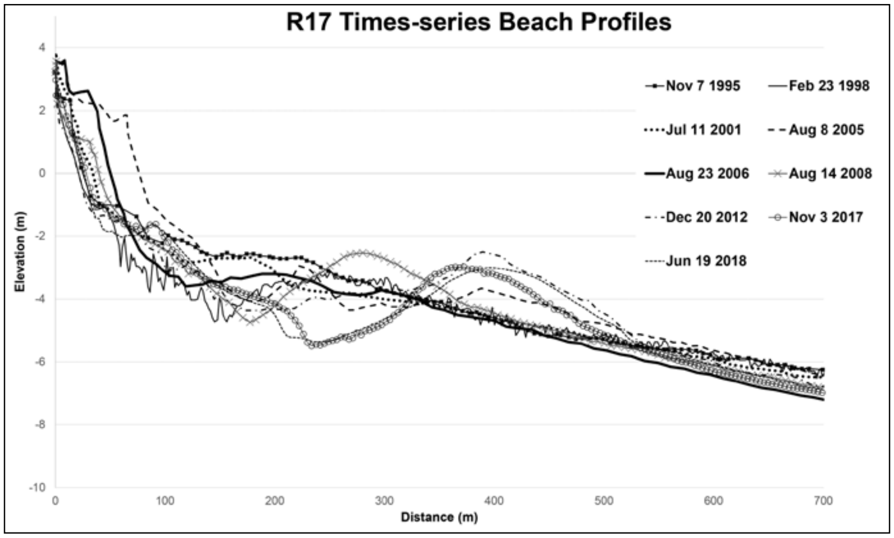

Figure 4. R17 time-series beach profiles across the study period.

Table 2

Recorded nourishment events during the study period.

Start year	Volume (m^3)
1995	461,791
1995	1,529
1996	1,331,192
2002	477,846
2003	1,161,788
2007	1,304,874
2012	879,894
2012	31,458
2013	4,664
2014	3,058
2015	34,634
2015	107,802
2015	62,758
2016	1,277,154
2017	78,037
2017	48,062
2019	896,823

(Figures 4 and 7), with offshore loss also observed at R21 (Figures 5 and 8). These deficits are likewise ascribed to impacts of Hurricanes Katrina and Wilma. The largest nearshore erosional event during this period was likely due to Hurricane Irma in 2017 (Figures 3-5). The largest volumetric loss above the shoreline was measured at R13 in 2012 coinciding with impacts from Hurricane Sandy, which occurred shortly after a major nourishment event (volume gain) the same year (Figure 6). The largest volumetric loss (~1,100 m^3) across the entire profile was measured following the active 2004-2005 hurricane season at R13 (Figure 6).

Nourishment and dredging impacts

Thirty-six reported dredging and nourishment projects occurred during the study period (Tables 2 and 3). A 1995 nearshore dredging event, using the Jupiter Inlet ebb-tidal shoal as a borrow source, reduced the nearshore elevation in the dredge pit by 5 m at R13 (Figure 3). In 1996, sand started to accumulate with near-complete infilling by 1997. At R17 in 2007, a total of 1,304,874 m^3 of sand was deposited at the study site, leading to nearshore accretion, as evident when comparing August 2006 to August 2008 (Figure 4). However, shortly prior to the August 2008 survey, Tropical Storm Fay impacted the area, resulting in a reduction of beach width. This event accelerated profile equilibration and led to subsequent beach loss. A volumetrically large nourishment event in 2012 was measured in all three profiles (Figures 3-8). Morphologic variability was measured following the nourishment event, and when coupled with the impact of Hurricane Sandy in October, a substantial loss of placed sand was measured in December 2012. In contrast, a volumetrically small quantity of BUDM from the inlet was placed solely at R13 in 2014, resulting in approximately 1.5 m of elevation gain above the shoreline, but no gain at the downdrift beaches. Minimal large-scale nourishments were constructed between 2012 and 2019, which may have allowed storm events to narrow the beach.

Inlet processes impacts

Large nearshore variability was measured at R13 due to dynamic inlet processes (Figure 3), with prominent migration of a nearshore sandbar at R17 (Figure 4) compared with less cross-shore variability in the sandbar at R21 (Figure 5). Morphologic variability at R17 is attributed to its proximity to the migratory ebb-tidal delta attachment point. In contrast, R21 is located farther from the inlet and the ebb-tidal delta attachment region, and, therefore, does not have the same large-scale patterns as the beaches influenced more heavily by complex inlet processes. Less overall and shoreline volumetric variability was measured at R21 (Figure 8) compared to R17 (Figure 7).

Decadal volume change

Decadal patterns of volume change were analyzed at each R-monument, with the average change between surveys within a decade demonstrating variable spatiotemporal patterns (Figure 9). Alongshore and cross-shore variability in volume change can be attributed to both natural and anthropogenic activities. The largest influences on volume loss were attributed to storms and downdrift influences of the structured inlet. However, BUDM and traditional beach nourish-

Table 3
Recorded dredging events at Jupiter Inlet during the study period.

Start year	Volume (m³)
1995	55,048
1996	24,114
1998	64,987
2000	42,968
2001	63,382
2002	33,640
2004	45,873
2005	59,635
2006	53,901
2008	67,156
2009	49,483
2010	67,267
2012	23,548
2013	52,460
2014	31,215
2015	34,660
2016	46,943
2017	48,066
2018	40,331

ment activities appear to be counterbalancing the loss in volume to some degree at the decadal scale, with less total volume loss over time.

During the 1990s and 2000s, R13 experienced a prevailing trend of total volume loss, but a modest subaerial gain in the same timeframe (Figure 9). The overall volume loss is likely a result of multiple consecutive storm events (Table 1); whereas the subaerial gain is attributed to the three significant nourishment activities over this period: 1996, 2004, and 2007 (Table 2). In the 2010s, the erosional trend underwent a distinctive shift to total volume gain at R13. This change is credited to the frequent succession of beach nourishment events and near annual placement of BUDM. It is likely that less subaerial volume was retained, in comparison with the total volume, due to the impacts of Hurricanes Sandy (2012) and Irma (2017). It seems frequent nourishment activities, with sediment primarily transported to the nearshore, contributed to overall positive volume change at R13. The magnitude of volumetric change at R17 was comparatively smaller than at R13. Although R17 experienced total volume loss in the 1990s and 2000s, a reverse to an average volume gain was observed in the 2010s, likely due to the management activities at this site coupled with sediment transport from the frequent nourishment at R13. Volumetric change in the 1990s at R21 was negligible.

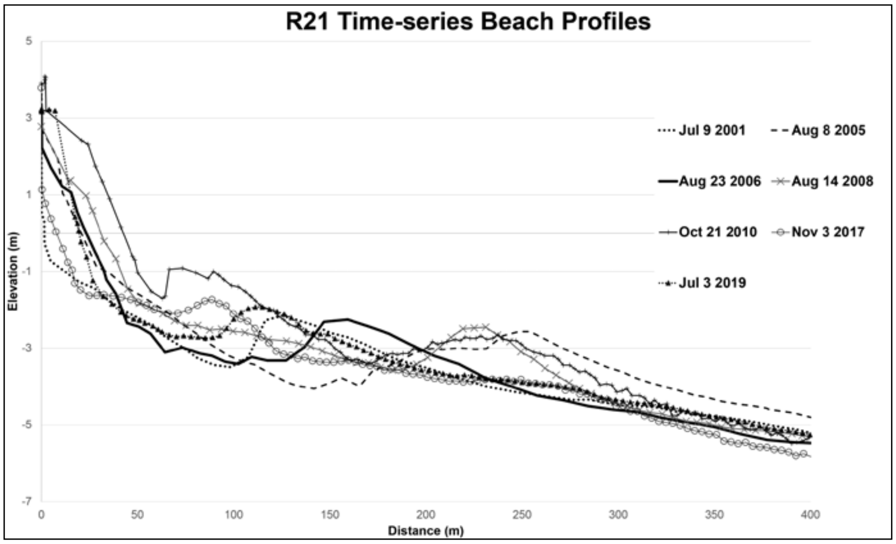

Figure 5. R21 time-series beach profiles across the study period.

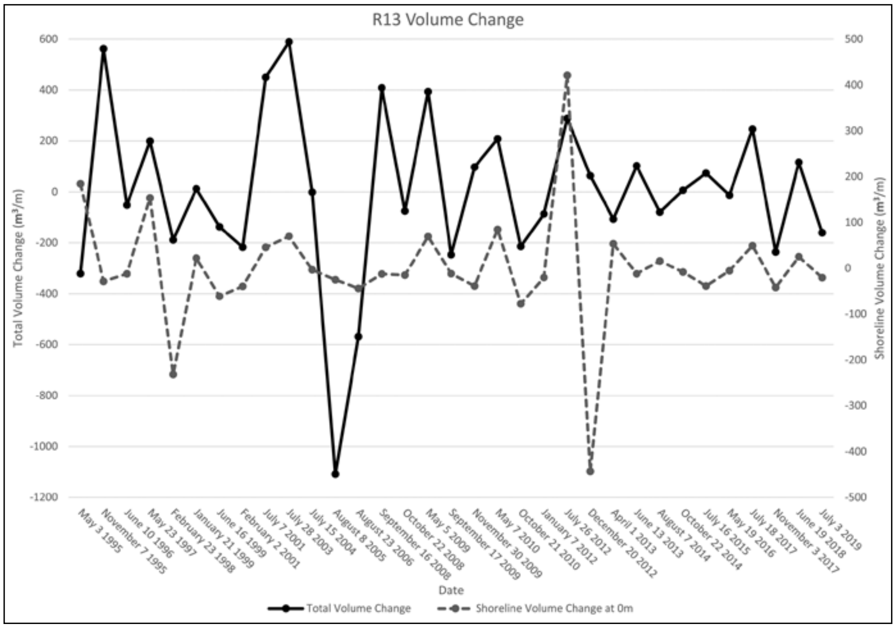

Figure 6. R13 total and shoreline volume change.

However, an average total volume loss and subaerial volume loss occurred at R21 during the 2000s. Yet, despite total volume loss persisting at R21 in the 2010s, the subaerial beach experienced volume gain. Some of the erosion is a likely consequence of Hurricanes Sandy (2012) and Irma (2017), as observed at R13 and R17. Still, it is reasonable to assume that the magnitude of total loss is considerably smaller than magnitudes experienced updrift due to longshore drift patterns transporting sediment southward from nourishment activities in the north (at R13 and R17) and sediment bypassing along the ebb-tidal delta. Of note is that R21 experienced a greater volume of subaerial loss compared to other beaches, which may be attributed to limitations on conventional beach nourishment practices at this location, where only dune restoration is permitted.

DISCUSSION

Inlet-adjacent beaches and barrier islands have complicated processes, with interactions driven by waves and tides at multiple spatiotemporal scales (Wang and Beck 2023). Understanding site-specific or regionally based long-term coastal change is necessary for characterizing both the human and natural influences of inlet-adjacent beaches for sustainable management strategies (Hein *et al.* 2019). Inlet-adjacent beaches can also serve as feeder beaches, whereby they act as a primary sediment source for downdrift beaches through the natural process of longshore drift (Elko and Wang 2007). Our data suggests the beach at R13 could

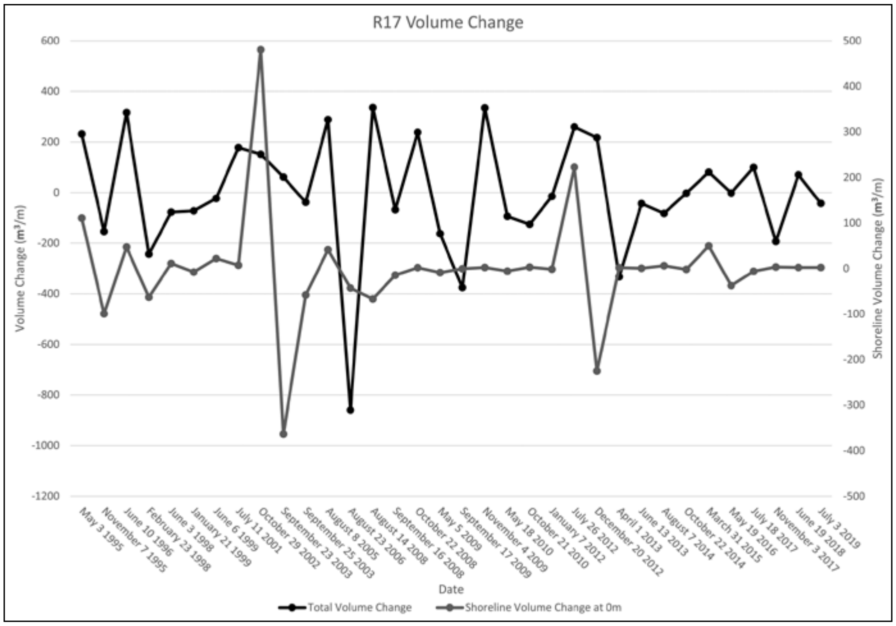

Figure 7. R17 total and shoreline volume change.

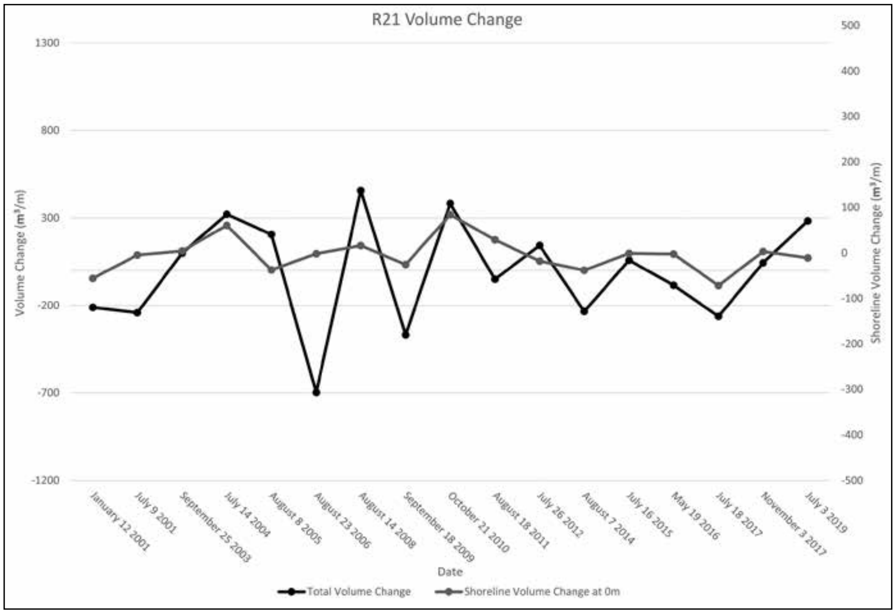

Figure 8. R21 total and shoreline volume change.

have been identified as a feeder beach in the 1990s and 2000s. During these two decades, erosion dominated at R13 while less volume loss was measured at the R17 beach and even less measured at the R21 beach. During this period, however, nourishment events were sparse and unevenly spaced. In the subsequent decade (i.e., 2010s), R13 had measured accretion coinciding with nourishment events occurring almost annually. This change in management strategy likely led to the retention of sediment within the R13 profile and provides evidence in support of more frequent nourishment activities at feeder beach locations. Roberts and Wang (2012) suggested a more frequent nourishment recurrence interval for feeder beaches to counter developing erosional hot spots. Larger future nourishments conducted at R13 could be an effective strategy to replenish the downdrift beaches via natural longshore sediment transport (R17/R21). Roberts and Wang (2012) also recorded increases in sediment volume observed at all the studied downdrift profiles with sand primarily being deposited in the intertidal zone. A similar pattern of sediment transport and volume change was also observed in this study area, where a reduction in sediment loss to the south is discernible when assessing total volume change but not by subaerial volume change alone. Furthermore, when the positive collateral effects of nourishment projects that were not originally designed for a feeder beach are documented, it helps counter the argument that all sediment leakages are losses (Nordstrom and Jackson, 2022).

FitzGerald *et al.* (2011) also noted that the transport of sand at a tidal inlet is complex due to the many influencing factors, including storm effects, reversing currents, and longshore drift. Sediment can naturally bypass the inlet, travelling across the ebb-tidal delta and supplying the downdrift beach; but this process is dependent on several factors, such as channel depth, ebb-tidal delta morphology, wave energy, seasonal variability, or anthropogenic influences (Beck *et al.* 2020). Burvingt *et al.* (2022) found that tidal inlet processes and formations affected nearshore bathymetry up to 10 km alongshore. In their assessment, the significant sediment volume changes downdrift of the inlet were allocated to the migration of sandy shoals. The behavior of the ebb-tidal delta, sediment bypassing to downdrift beaches, and the influence of the inlet on nearshore bathymetry observed by Burvingt *et al.* (2022) is consistent with our results. However, results of this study suggest that the impact of the inlet was minimal at R21, and therefore, at this site, the effects of the inlet extend less than 3 km downstream. The variability in the downdrift ebb delta attachment and other impacts observed in this study have also been shown in other studies, in which tidal prism and wave-energy exposure play a significant role (Carr-Betts *et al.* 2012)

While our study was exploratory by design to provide valuable initial observations with only a limited number of profiles along the coast, it is important to acknowledge the study's potential for greater spatial resolution. Although it would be more time-consuming, expanding research to encompass more, if not all, profiles along the Jupiter Inlet coastline could achieve a more comprehensive understanding of morphological changes and influences. On the other hand, if the results of a more detailed analysis would not provide additional insight beyond the selected spacing of the profiles analyzed with respect to the historic ebb-tidal delta attachment point, then perhaps this study supports a methodology for rapid assessment of decadal-scale trends of inlet-adjacent beaches. Additional studies should also explore the effects of storms and nourishment events on inlet-adjacent beaches using advanced remote sensing techniques that could offer continuous, or frequent, real-time data collection that may be used to cover large areas and integrated into coastal models. Conlin *et al.* (2022) found that surf cameras using SurfRCaT (Surf-Camera Remote Calibration Tool) provide a practicable source of coastal morphodynamic observations. When coupled with traditional erosion observation methods, technological advancements in remote sensing provide a holistic view of coastal dynamics, enhancing the accuracy of findings. Historical data can also inform future projections of coastal change and management needs. Vitousek *et al.* (2017) integrated historical shoreline data into the CoSMoS-COAST shoreline change model, which enhanced model parameters and resulted in improved overall accuracy in replicating changes from the 1990s to the 2010s. The model was subsequently employed to project future shoreline positions based on long-term historical shoreline change rates.

CONCLUSIONS

This study quantified morphological variabilities of three inlet-adjacent beaches in Jupiter, Florida, over the past three decades. The beach and shoreline variability were found to be primarily driven by proximity to a structured inlet and major consecutive storm events. A decrease in cross-shore morphology change coincided with an increase in distance from the inlet. The largest changes to the shoreline and nearshore regions were associated with periods of higher storm activity and nourishment initiatives, with the largest decadal variability measured at profiles closest to Jupiter Inlet. Over the past decade, frequently nourished locations had an average total volume gain, in contrast with locations where only dune restoration is permitted without beach nourishment. Ultimately, decadal morphological shifts were found to be driven by variations in storm events, beach nourishment trends, and longshore sediment transport.

ACKNOWLEDGMENTS

We are grateful to the Florida Atlantic University Office of Undergraduate Research & Inquiry, which funded this research as a joint student project (Summer 2021), and we thank Ph.D. student Tynon Briggs for his mentorship during that time.

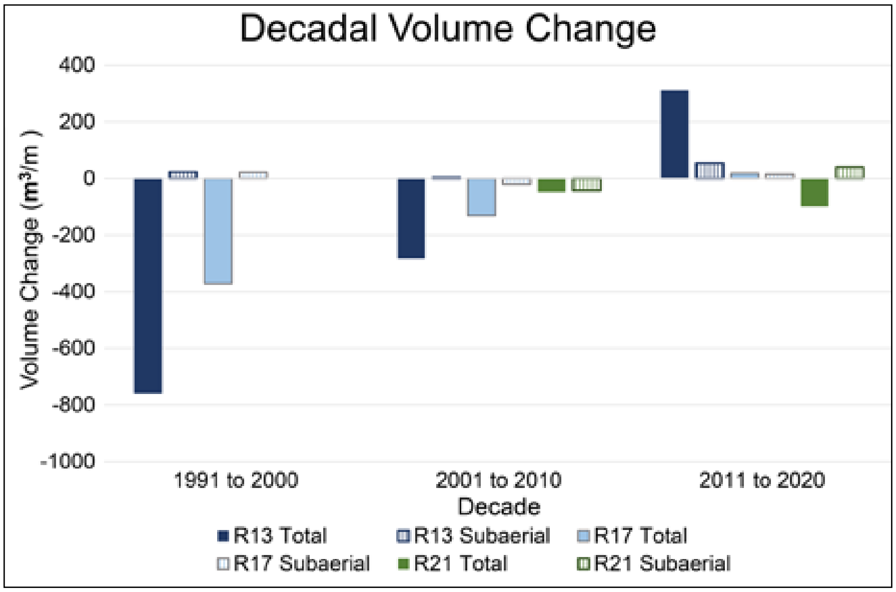

Figure 9. Decadal subaerial and total profile volume change.

REFERENCES

Adams, P.N., Keough, K.M., and M. Olabarrieta, 2016. "Beach Morphodynamics influenced by an ebb-tidal delta on the north Florida Atlantic coast." *Earth Surf. Process. Landforms*, 41: 936-950. doi: 10.1002/esp.3877.

American Shore and Beach Preservation Association (2009-2022). National Beach Nourishment Database. https://gim2.aptim.com/ASBPANationwideRenourishment/.

Beck, T.M., Wang, P., Li, H., and W. Wu, 2020. "Sediment bypassing pathways between tidal inlets and adjacent beaches." *J. Coastal Research*, 36(5), 897-914. doi: 10.2112/JCOASTRES-D-19-00141.1

Briggs, T.R., Brown, N., and M.S. Priddy, 2021. "Subaerial beach morphology change from multiple storms during the 2020 hurricane season." *Shore & Beach*, 89(2), 65-74.

Bruun, P., 1996. "The development of downdrift erosion." *J. Coastal Research*, 11(4): 1242-1257.

Burvingt, O., Lerma, A.N., Lubac, B., Mallet, C., and N. Senechal, 2022. "Geomorphological control of sandy beaches by a mixed-energy tidal inlet." *Marine Geology,* 450: 106863.

Carr-Betts, E., Beck, T.M., and N.C. Kraus, 2012. "Tidal inlet morphology classification and empirical determination of seaward and down-drift extents of tidal inlets." *J. Coastal Research*, 28(3), 547-556.

Cheng, J., Wang, P., and Q. Guo, 2016. "Measuring beach profiles along a low-wave energy microtidal coast, west-central Florida, USA." *Geosciences*, 6(4), 44. doi: 10.3390/geosciences6040044

Conlin, M.P., Adams, P.N., and M.L. Palmsten, 2022. "On the potential for remote observations of coastal morphodynamics from surf-cameras." *Remote Sensing*, 14(7), 1706. doi: 10.3390/rs14071706

Elko, N.A., and P. Wang, 2007. "Immediate profile and planform evolution of a beach nourishment project with hurricane influences." *Coastal Engineering*, 54(1), 49-66. doi: 10.1016/j.coastaleng.2006.08.001

FitzGerald, D.M., 1996. "Geomorphic variability and morphologic and sedimentary controls on tidal inlets." *J. Coastal Research*, 23: 47-71.

FitzGerald, D., Buynevich, I., and C. Hein, 2011. "Morphodynamics and facies architecture of tidal inlets and tidal deltas." *Principles of Tidal Sedimentology*, 301-333. doi: 10.1007/978-94-007-0123-6_12

Florida Department of Environmental Protection (FDEP), 2021. "Critically eroded beaches in Florida." https://floridadep.gov/

Galgano, F.A., 2009. "Beach erosion adjacent to stabilized microtidal inlets." *Middle States Geographer*, 42: 18- 32 https://msaag.aag.org/wp-content/uploads/2013/04/3_GALGANO.pdf

Itzkin, M., Moore, L.J., Ruggiero, P., Hacker, S.D., and R.G. Biel, 2021. "The relative influence of dune aspect ratio and beach width on dune erosion as a function of storm duration and surge level." *Earth Surface Dynamics*, 9, 1223-1237. doi: 10.5194/esurf-9-1223-2021.

Karunarathna, H., Pender, D., Ranasinghe, R., Short, A.D., and D.E. Reeve, 2014. "The effects of storm clustering on beach profile variability." *Marine Geology*, *348*, 103-112. doi: 10.1016/j.margeo.2013.12.007.

National Centers for Environmental Information, 2020. "Storm Events Database." https://www.ncdc.noaa.gov/stormevents/.

Nordstrom, K.F., and N.L. Jackson, 2022. "Beach nourishment and impacts." In *Beach and Dune Restoration*, 2nd ed., pp. 26-64. Cambridge: Cambridge University Press.

Roberts, T.M., and P. Wang, 2012. "Four-year performance and associated controlling factors of several beach nourishment projects along three adjacent barrier islands, west-central Florida, USA." *Coastal Engineering*, 70, 29-39.

Vitousek, S., Barnard, P.L., Limber, P., Erikson, L., and B. Cole, 2017. "A model integrating longshore and cross-shore processes for predicting long-term shoreline response to climate change." *J. Geophysical Research: Earth Surface*, 122, 782-806, doi: 10.1002/2016JF004065.

Wang, P., and T. Beck, 2023. "Beach-inlet interaction and regional sediment management at pristine and developed barrier islands." *International Proc. Coastal Sediments 2023,* 1737-1751.