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BEACH MORPHOLOGY AND SEDIMENTOLOGY IN NORTHERN PALM BEACH COUNTY, FLORIDA, USA: A BRIEF UPDATE

MORFOLOGIA E SEDIMENTOLOGIA DE PRAIA NO CONDADO DE NORTHERN PALM BEACH, FLORIDA, EUA: UMA BREVE ATUALIZAÇÃO

MORPHOLOGIE ET SÉDIMENTOLOGIE DES PLAGES DANS LE COMTÉ DE NORTHERN PALM BEACH, FLORIDE, ÉTATS-UNIS : UNE BRÈVE MISE À JOUR

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ABSTRACT
Coastal erosion of sandy beaches is a global problem that threatens ecosystems and coastal communities. Beach nourishment is one of the commonly implemented mitigation strategies, using beach compatible sediment from various borrow sources that is placed on beaches and back in the littoral system. However, the geotechnical properties of sediment from different borrow sources can vary. Sediment characteristics influence post-nourishment equilibration, beach slope, substrate temperatures for incubating sea turtles, and morphologic response to storms. Although many regulatory agencies have policies requiring that the borrow source sediment closely matches, or is compatible with, the native beach sediment, placement of sediment from various borrow sources could result in sediment properties that deviate from the native material over time due to selective transport processes. This study is a brief update on the results of Brown and Briggs (2020) on the sediment properties and beach morphology of nourished and non-nourished beaches in northern Palm Beach County, FL, USA. Nourished beaches using various borrow sources were similar in sedimentology and slope to non-nourished beaches. Foreshore slopes on local beaches were most similar to predicted slopes for protected beaches, likely due to reduced fetch from the Bahamian archipelago. The proximity to hard structures appears to have an important influence on foreshore slopes and sediment properties and requires further analysis.
Keywords: Sediment; Beach slope; Nourishment

RESUMO
A erosão costeira de praias arenosas é um problema global que ameaça os ecossistemas e as comunidades costeiras. A engorda das praias é uma das estratégias de mitigação comumente implementadas, usando sedimentos compatíveis com as praias de várias fontes de empréstimo que são colocadas nas praias e no sistema litoral. No entanto, as propriedades geotécnicas dos sedimentos de diferentes fontes de empréstimo podem variar. As características do sedimento influenciam o equilíbrio pós-engorda, a inclinação da praia, as temperaturas do substrato para a incubação das tartarugas marinhas e a resposta morfológica às tempestades. Embora muitas agências reguladoras tenham políticas exigindo que o sedimento da fonte de empréstimo corresponda ou seja compatível com o sedimento nativo da praia, a colocação de sedimentos de várias fontes de empréstimo pode resultar em propriedades do sedimento que se desviam do material nativo ao longo do tempo devido a processos de transporte seletivo . Este estudo é uma breve atualização dos resultados de Brown e Briggs (2020) sobre as propriedades dos sedimentos e a morfologia de praias de engorda e praias naturais no norte de Palm Beach County, FL, EUA. Praias que passaram por engorda usando várias fontes de empréstimo foram semelhantes em sedimentologia e declive à praias naturais. A declividade da faixa de praias locais foram mais semelhantes às inclinações previstas para praias protegidas, provavelmente devido à redução do fetch oriundo do arquipélago das Bahamas. A proximidade de estruturas duras parece ter uma influência importante nas faixa de praia e nas propriedades dos sedimentos o que requer uma análise mais aprofundada.
Palavras-chave: Sedimento; inclinação de praia; engorda de praia.

RÉSUMÉ

L'érosion côtière des plages de sable est un problème mondial qui menace les écosystèmes et les communautés côtières. Le rechargement des plages est l'une des stratégies d'atténuation couramment mises en œuvre, utilisant des sédiments compatibles avec les plages provenant de diverses sources d'emprunt qui sont placés sur les plages et dans le système littoral. Cependant, les propriétés géotechniques des sédiments provenant de différentes sources d'emprunt peuvent varier. Les caractéristiques des sédiments influencent l'équilibre post-alimentation, la pente de la plage, les températures du substrat pour l'incubation des tortues marines et la réponse morphologique aux tempêtes. Bien que de nombreux organismes de réglementation aient des politiques exigeant que les sédiments de source d'emprunt soient compatibles avec les sédiments de plage naturel, le placement de sédiments provenant de diverses sources d'emprunt pourrait entraîner des propriétés de sédiments qui s'écartent du matériau indigène au fil du temps en raison de processus de transport sélectifs. Cette étude est une brève mise à jour des résultats de Brown et Briggs (2020) sur les propriétés des sédiments et la morphologie des plages nourries et non nourries du nord du comté de Palm Beach, en Floride, aux États-Unis. Les plages alimentées utilisant diverses sources d'emprunt étaient similaires en sédimentologie et en pente aux plages non alimentées. Les pentes de l'estran sur les plages locales étaient les plus similaires aux pentes prévues pour les plages protégées, probablement en raison du fetch provenant de l'archipel des Bahamas. La proximité de structures dures semble avoir une influence importante sur les pentes de l'estran et les propriétés des sédiments et nécessite une analyse plus approfondie

Mots Clés: Sédiment ; versant de plage ; alimentation de plages.

INTRODUCTION

Coastal environments provide habitat for various species, protect coastal communities from storm impacts and reduce coastal flooding, have cultural importance, and play a major role in local and state economies, especially in Florida. Today, more than 10% of the global population lives within 10 m of the present sea level (de Schipper et al. 2021), despite increased vulnerability from risks associated with global warming. Increases in major storms, rising sea level, lack of sand input from rivers, and anthropogenic activities are contributing to the erosion of sandy beaches worldwide (Chiva et al. 2018; Leatherman et al. 2000). One of the leading forms of coastal protection and mitigation in the U.S., including southeast Florida, is beach nourishment (Elko et al. 2021). Beach nourishment places “beach quality” sand from various borrow sources such as upland, offshore, or nearby inlet sources to restore sediment that has been eroded and widen the beach (Wilson et al. 2017). Dune restoration can accompany beach nourishment projects or in some cases is the only option in locations where placing sediment directly on a beach might result in adverse impacts to nearshore reefs or outcropping hardbottom.

Suitable sand sources for beach fill material are found in offshore or upland sites or from the beneficial use of dredged sediment from nearby channel maintenance (also referred to as BUDM) (Stauble 2007). It is important for borrow sources to closely match the native beach material since sediment properties are known to influence post-nourishment equilibration, beach slope, morphologic response to storms, beach use, and tourist attractiveness (Pranzini et al. 2018; CEM 2003; Larson and Kraus 1991; Pranzini et al. 2011). Sediment characteristics of interest include mean and median grain size, sorting, skewness, silt content, carbonate content, organic content, minerology, and color (Coor et al. 2017). In the state of Florida, sand quality is regulated by the Florida Department of Environmental Protection (FDEP). Numerous policies are in place to ensure that mean grain size and Munsell color of placed sediment are similar to the native sediment (FDEP 2017). For beach nourishment projects designed for multi-year coastal storm damage reduction, FDEP requires that no more than 5% of silt can pass through the #230 sieve and up to 5% of material can be retained on the #4 sieve (FDEP

2017; ASBPA & CSO 2022). However, where sediment is placed as beneficial use of dredge material (BUDM) to maintain sediment within the littoral system, up to 10% of finer than sand-sized grains are permitted for placement.

Sediment properties might vary overtime from restoration activities that use different borrow sources or from natural selective transport processes (FDEP 2016; Brown and Briggs 2020). For example, Brown and Briggs (2020) found sediment texture varied alongshore and cross-shore for natural (non-nourished) and nourished beaches in Palm Beach County, Florida. The goal of this study is to provide a brief update on the sediment properties and beach morphology of nourished and non-nourished barrier island beaches in northern Palm Beach County, Florida, USA over a four-year period (2019-2022).

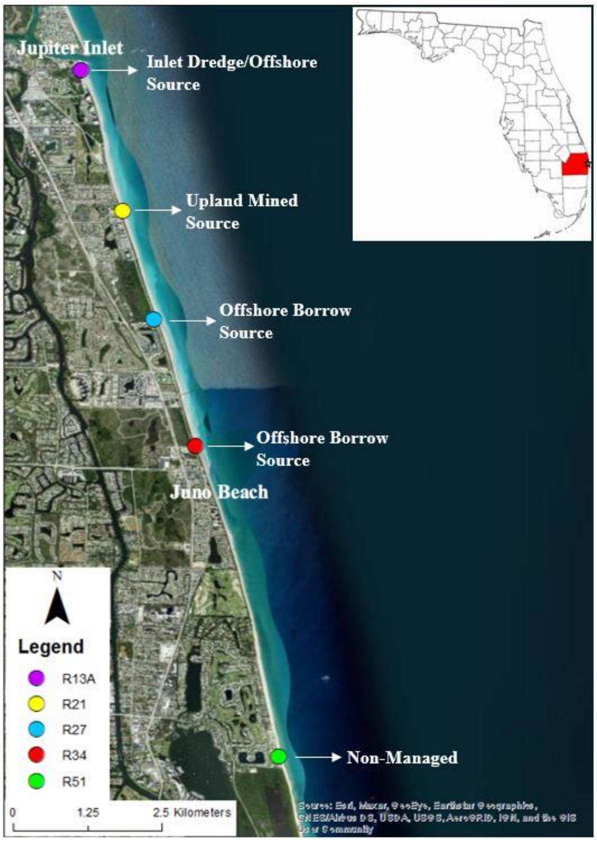
STUDY AREA

Palm Beach County (PBC) has 75-km of coastline in southeast Florida. Sediment on beaches in PBC have an average grain size of 0.51 mm near the shoreline (i.e., at mean sea level). Sediment is mainly composed of terrigenous quartz and calcareous fragments from eroded coquina outcrops and biogenic shell (Finkl et al. 2003; Brown and Briggs 2020). Approximately 54-km of PBC beaches have been designated as critically eroded (FDEP 2022). To mitigate adverse impacts of coastal erosion, beach nourishment and dune restoration are common in PBC (ASBPA National Beach Nourishment Database 2022).

This study evaluates the sediment and morphology at 5 locations in northern PBC over a four-year period between 2019-2022. Sites selected include managed (beach and/or dune nourishment) and non-managed beaches (non-nourished/control) aligning with R-monuments at R13A, R21, R27, R34, and R51 (Figure 1). Inlet dredge material is placed at or near R13A on a near annual basis, sometimes supplemented with sediment from an offshore borrow source. R21 is located in an area that uses an upland mine source. Beaches at R27 and R34 are nourished using an offshore borrow source. The beach at R51 has not been nourished and is used as a control for comparison to managed beaches.

The northern-most inlet-adjacent location at R13A placed ~21,400 m^3 of inlet dredge sediment in early 2019 (PBC ERM 2022). The following year (2020), ~382,280 m^3 of offshore borrow sediment was placed along ~1.7 km that included R13A as part of the Palm Beach County North County Comprehensive Shoreline Protection Project. In early 2021, ~160,560 m^3 of inlet dredge material was placed at R13A. Also in 2021, an additional 312,700 m^3 of material was placed along the same 1.7 km of beach using an offshore borrow source. A small dune restoration project was completed in 2020 at R21with 3,820 m^3 of sediment from an upland mine source used to restore the dunes. In 2022, an additional 34,565 m^3 of sediment from the upland mine was placed at R21 for dune restoration. Beaches at R27 and R34 in Juno Beach were nourished in 2021 as part of the North County Comprehensive Shoreline Protection Project that placed 917,465 m^3 of sediment from an offshore borrow source.

Figure 1. Palm Beach County (red) is located in southeast Florida (source: Wikimedia Commons). This study evaluated 5 locations including managed beaches that place sediment from various borrow sources and a non-managed beach in northern Palm Beach County, FL.



Source: the authors

METHODOLOGY

Data was obtained from Brown & Briggs (2020) for beach profile and sediment properties in 2019 and used for comparison to the data collected in 2020-2022 for this study. Sediment samples were collected from the surface at the dune toe (or high beach, "H"), mid-beach (or mid, "M"), and Mean High Water/MHW (or low beach, "L") from 2020-2022 at the five locations. A total of 45 sediment samples were analyzed for bulk sediment statistics. Sediments were sieved using a W.S. Tyler Ro-Tap Mechanical Sieve Shaker and standard 8" full-height brass test sieves at half phi intervals between -4 and 2 ϕ and quarter phi intervals between 2 and 4 ϕ (where ϕ is a negative logarithmic scale). Percent carbonate was determined by hydrochloric acid dissolution. Statistical analysis using the moment method was used to determine mean, median, and standard deviation (i.e., sorting) for the bulk sample (Boggs 2012).

Beach profile surveys (xyz) were completed from the dune (or other physiographic delineation of the landward extent of the beach environment) to the swash zone using Real-Time Kinematic (RTK) Global Positioning System (GPS). Beach profiles were surveyed annually from 2020-2022 in early spring (between March-May) with the seaward extent of data collection dependent on the tidal stage. The foreshore slope was measured between 1.0 m to 0 m elevation (NAVD88). During some surveys, spring high tide prevented accessing the 0 m elevation (i.e., it was submerged), so the foreshore slope was calculated based on the seaward-most surveyed points' cross-shore location and elevation. Measured slopes were compared with the McFall (2019) predictive equation for protected, moderately protected, and exposed beaches using the median grain size (mm) from the mean high water (MHW) sediment samples. Predictions for each beach exposure were based on the inverse beach face slope (X):

$$X = A\, d^{\,n}$$

McFall (2019) used 181 samples to estimate the beachface slope for three beach exposure types as follows:

Protected: $X = 3.1\, d^{-1.1}$

Moderately protected: $X = 2.1\, d^{-1.8}$

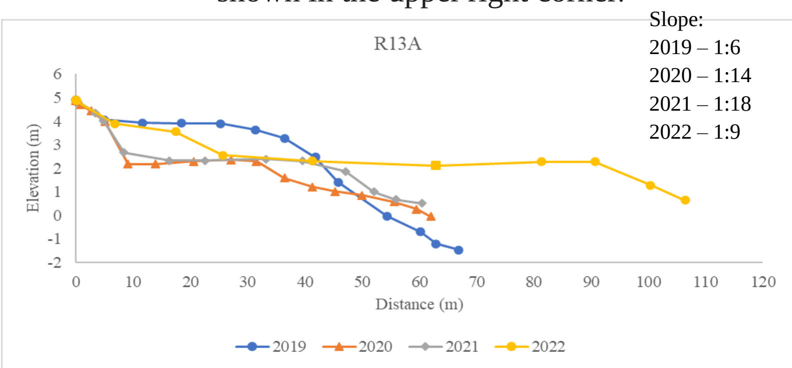
Exposed: $X = 3.9\, d^{-1.85}$

RESULTS

MORPHOLOGY

Inlet dredge material and offshore borrow material were placed annually at R13A. After placement of BUDM in 2019, the beach profile consisted of a 20 m berm and gently sloping backbeach and foreshore (Figure 2). In 2020, the beach was nourished using a different elevation template and an offshore borrow source. The beach profile consisted of a wide beach with a gently sloping foreshore. Placement of BUDM was completed in 2021 with volume gain primarily advancing the berm crest. In December 2021, offshore sediment was placed prior to the 2022 survey, widening the beach by 40 m and increasing the backbeach elevation by 1.5 m. The slope measured at R13A was steepest in 2019 with a 1:6 ratio. The foreshore slope began to decrease to a more gently sloping foreshore (1:14) in 2020 and 2021 (1:18). In 2022, a steeper foreshore slope was measured (1:9) after the recent beach nourishment that advanced the shoreline >55 meters seaward of the 2019 location.

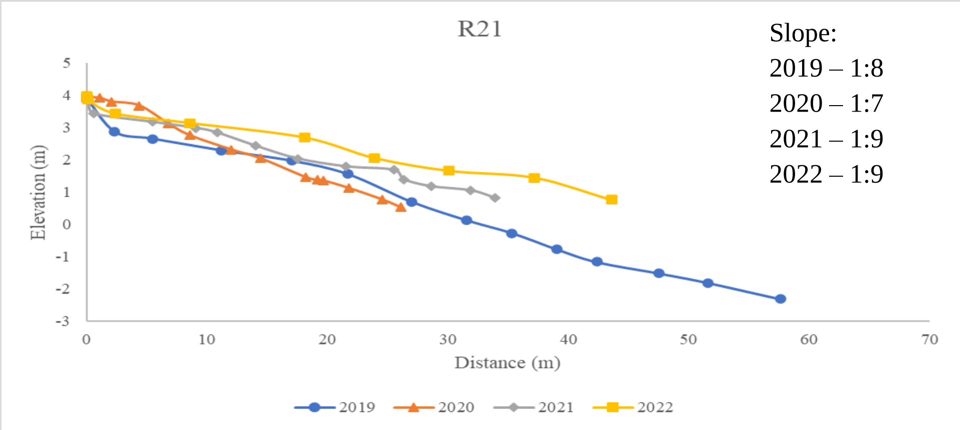
Figure 2. Beach profiles from 2019-2022 at R13A with annual foreshore slope calculations shown in the upper right corner.



Source: the authors

Dune restoration projects were completed at R21 in 2020 and 2022 using an upland mine source for sediment. Sediment accretion was measured on the backbeach between 2019 and 2020 followed by some erosion of the backbeach in 2021. However, seaward advance of the foreshore began in 2021 and continued into 2022. A second, larger dune restoration project was completed in 2022 and the shoreline was >10 meters seaward of its 2019 location. The foreshore slope remained consistently between 1:7 and 1:9 for all four years.

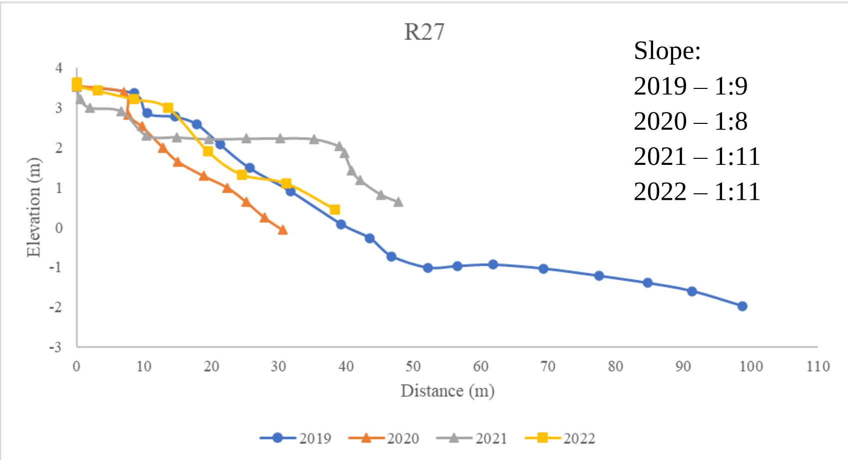
Figure 3. Beach profiles from 2019-2022 at R21 with annual foreshore slope calculations shown in the upper right corner.



Source: the authors

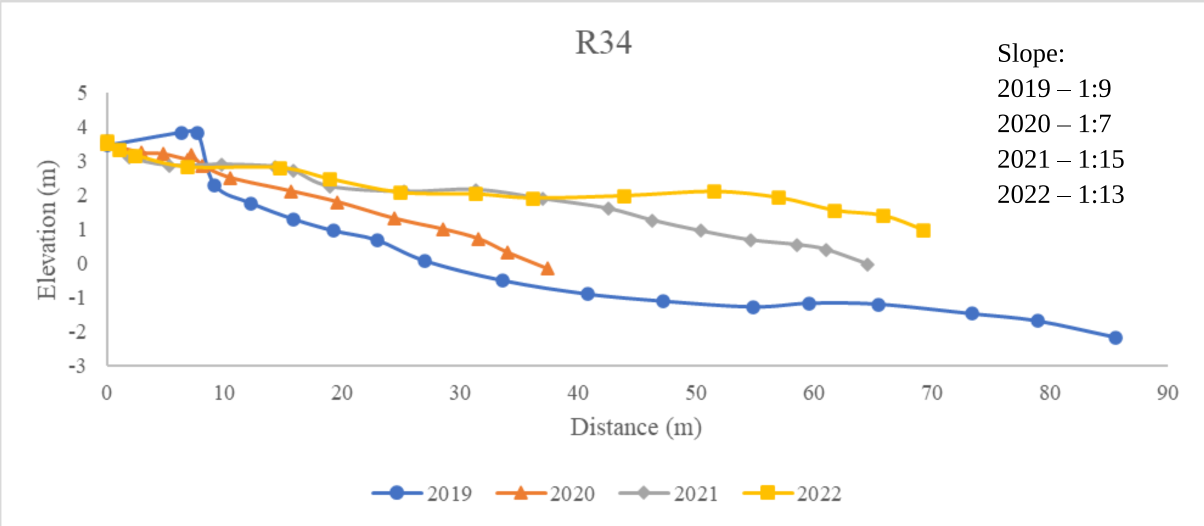
R27 and R34 are located along beaches nourished with an offshore borrow source. The beach profile at R27 initially consisted of a steeply sloped backbeach and foreshore (Figure 4). After placement of sediment from the offshore borrow source in 2021, the beach gained 1 m elevation and consisted of a wide planar berm and gently sloping foreshore despite elevation loss on the backbeach. However, the backbeach recovered by 2022 and the shoreline was in the same approximate location as it was in 2019. Between 2019 and 2020, the elevated backbeach at R34 was removed and the beach regraded (Figure 5). The placement of offshore material in 2021 widened the beach by 20 m and resulted in a gentler slope (1:15). By 2022, the shoreline was ~40 meters seaward of the 2019 location. Placement of offshore borrow material resulted in a more gently sloping foreshore at both R27 and R34, 1:11 and 1:15 respectively.

Figure 4. Beach profiles from 2019-2022 at R27 with annual foreshore slope calculations shown in the upper right corner.



Source: the authors

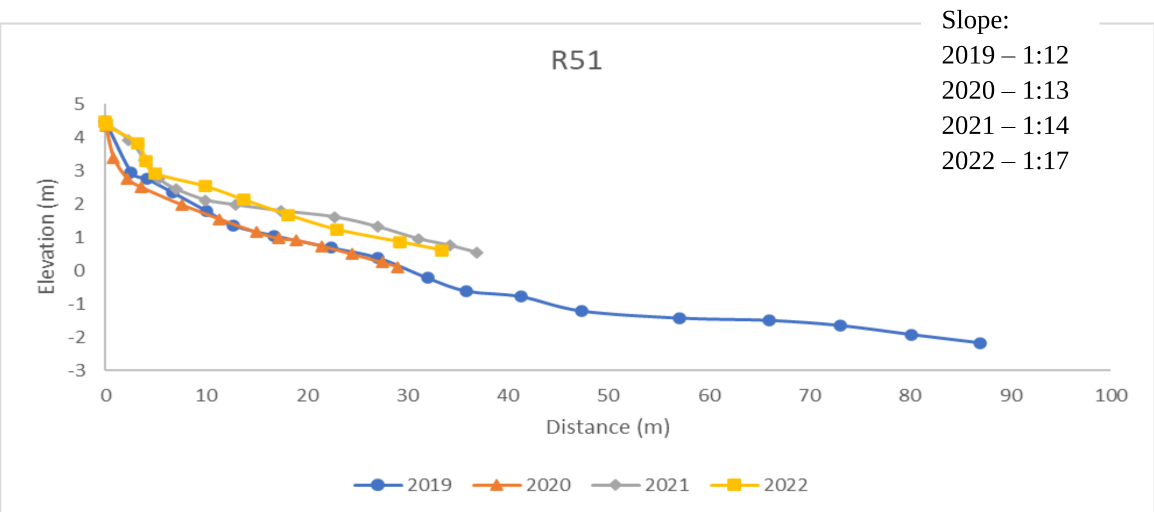
Figure 5. Beach profiles from 2019-2022 at R34 with annual foreshore slope calculations shown in the upper right corner.



Source: the authors

The southernmost location at R51 is a non-nourished beach. The beach profile was seaward sloping with no visible berm and very little change in morphology in 2019 and 2020 (Figure 6). Elevation gain on the backbeach and across the entire profile was measured in 2021. Slight erosion of the foreshore and backbeach accretion was measured in 2022 but the shoreline was no more than 10 m seaward of the 2019 location. The foreshore slope became slightly gentler between 2019 (1:12) to 2022 (1:17).

Figure 6. Beach profiles from 2019-2022 at R51 with annual foreshore slope calculations shown in the upper right corner.



Source: the authors

SEDIMENTOLOGY

Bulk sediment properties varied alongshore and at each cross-shore location from the dune toe (high, or "H"), mid-beach (mid, or "M"), and MHW (low, or "L") (Table 1). Mean grain size

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ranged from 0.41-1.83 φ between 2019 and 2022. The coarsest sediment was documented at R13A in 2019 with mean grain size ranging between 0.41-0.92 φ. However, the finest sediment was also found at R13A in 2021 with mean grain sizes ranging between 1.19-1.62 φ. Sorting ranged from 0.41-1.92 φ, with the best sorting at R51 (0.48-0.54 φ) and the most poorly sorted sediment at R27 (1.56-1.62 φ). Carbonate content ranged from 20-93% with the highest carbonate content generally occurring at R13A (64-82%).

Table 1. Bulk Sediment Data from 2019-2022.

Sample #	Year	Mean (φ)	Sorting (φ)	% Carbonate
R13A H	2019	0.92	0.91	70
R13A M		0.41	1.21	76
R13A L		0.49	1.13	82
R21 H		1.41	0.59	47
R21 M		1.04	0.76	59
R21 L		1.61	0.54	40
R27 H		1.30	0.50	46
R27 M		1.18	0.66	47
R27 L		1.47	0.53	43
R34 H		0.91	0.51	54
R34 M		1.21	1.08	56
R34 L		1.83	0.53	43
R51 H		1.25	0.54	50
R51 M		1.22	0.51	52
R51 L		1.41	0.48	48
R13A H	2020	0.91	0.85	45
R13A M		1.33	0.61	69
R13A L		1.60	0.76	64
R21 H		0.97	0.75	20
R21 M		1.10	0.73	67
R21 L		1.10	0.72	66
R27 H		0.69	0.84	55
R27 M		1.41	0.54	47
R27 L		1.63	0.49	39
R34 H		1.15	0.59	51
R34 M		1.01	0.68	56
R34 L		1.52	0.66	44
R51 H		1.24	0.50	50
R51 M		1.35	0.54	49
R51 L		1.15	0.52	48
R13A H	2021	1.62	0.56	64
R13A M		1.19	0.94	71
R13A L		1.37	0.72	71
R21 H		1.57	0.45	51
R21 M		1.39	0.56	63
R21 L		1.19	0.56	66
R27 H		1.42	0.57	61
R27 M		0.93	1.92	75
R27 L		1.58	0.81	66
R34 H		0.87	1.23	68
R34 M		1.01	1.40	68
R34 L		1.75	0.49	69
R51 H		1.38	0.83	39
R51 M		1.22	0.99	43
R51 L		0.99	0.72	58

R13A H	2022	1.09	0.76	72
R13A M		1.37	0.73	70
R13A L		1.70	0.56	64
R21 H		1.64	0.41	39
R21 M		1.62	0.49	65
R21 L		0.65	0.57	93
R27 H		1.57	0.45	47
R27 M		1.56	0.63	57
R27 L		1.62	0.77	56
R34 H		1.6	0.51	57
R34 M		1.00	0.87	70
R34 L		0.82	1.42	53
R51 H		1.38	0.45	53
R51 M		1.01	0.52	62
R51 L		1.52	0.50	46

Source: the authors

In 2019, sediment at R13A was generally the coarsest in the study area. Sediment then became finer and better sorted in 2020-2022 with poorly sorted to moderately well sorted coarse to medium sand (Figures 7 and 8). In 2019, sediment was well-sorted at dune toe with more poor sorting towards the MHW. Sediment remained coarse at the dune toe in 2020 but became finer at the mid-beach and MHW. A reverse trend was measured in 2022 with better sorting at the MHW compared to the dune toe. Carbonate content was generally highest at R13A throughout the study period ranging between 64 to 82% (for all but one instance of only 45% carbonate content at the dune toe in 2020).

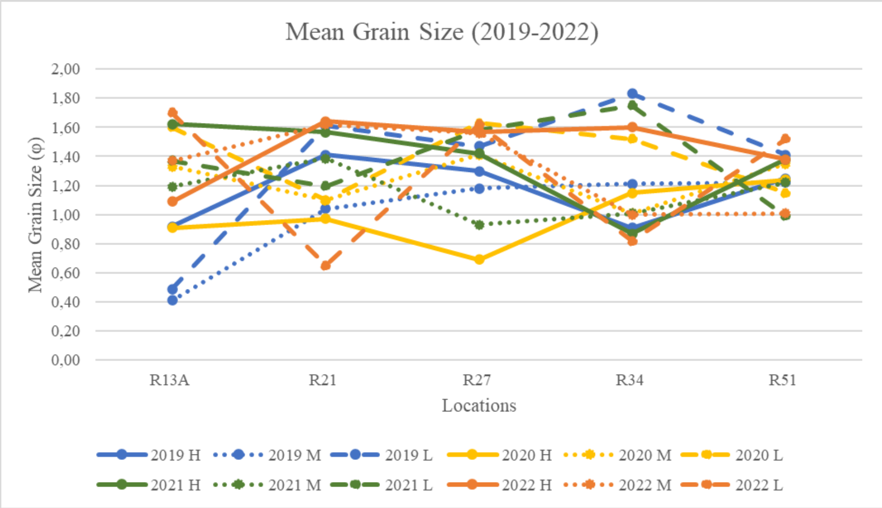
Variability in sediment from the dune toe to the MHW from 2019-2022 was measured at R21. Sediment at R21 in 2019 was moderately to moderately well sorted medium sand. After placement of upland mined material in 2020, sediment became coarser at the dune toe but remained moderately to moderately well sorted medium sand at the mid beach to MHW. In 2021, sediment was finer at the dune toe and remained consistent at the cross-shore locations with well to moderately well sorted medium sand. After the upland mine sediment was placed at the dune in 2022, the dune toe and mid-beach had medium sand but sediment coarsened from medium sand to coarse sand at the MHW. The largest variability in carbonate content was measured at R21 from 2019-2022 with a range of 20-93%.

Sediment was moderately well sorted medium sand at all cross-shore locations at R27 in 2019. Sediment began to coarsen at the dune toe from medium to coarse sand and was medium sand at the mid-beach and MHW in 2020. Sediment became better sorted from the dune toe to the MHW in 2020. Sediment coarsened and became more poorly sorted at the mid-beach in 2021 after placement of an offshore borrow source for beach nourishment. The dune toe and MHW had moderately to moderately well sorted medium sand. From 2021-2022 the mid-beach went from coarse to medium sand and the dune toe and mid-beach had medium sand. In 2022, sediment became more poorly sorted from the dune toe to the MHW. Carbonate content of sediment ranged from 39-75% from 2019-2022.

R34 was nourished in 2021 using the same template and offshore source material as R27. However, the most variability across a single transect over the study period occurred at R34. In 2019, sediment was moderately well sorted, coarse sand at the dune toe and poorly sorted, medium sand at the mid-beach becoming well sorted, medium sand at the MHW. In 2020, sediment was moderately well sorted medium sand. However, after nourishment in 2021 using the offshore borrow source, sediment was coarser at the dune toe. In 2022, finer sediment was found at the dune toe with coarser sediment at the MHW. Carbonate content ranged from 43-70% from 2019-2022.

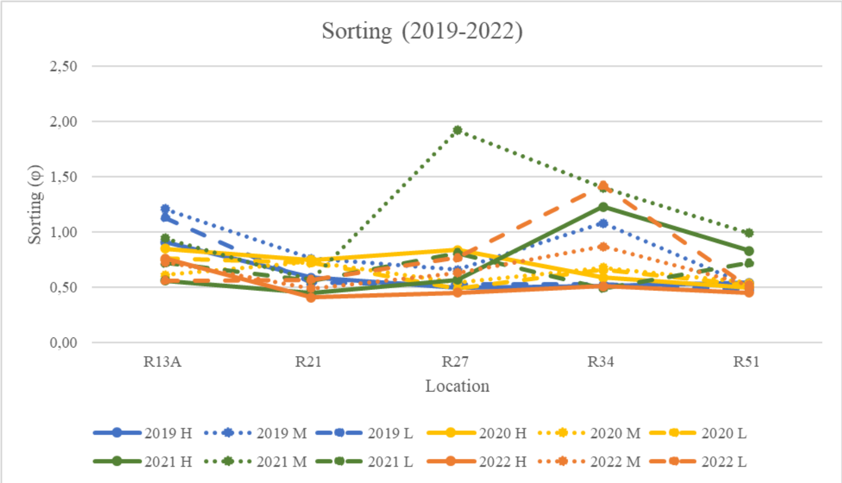
The control site at R51 has no documentation of nourishment. Sediment at R51 was the most consistent with moderately to well sorted medium sand. In 2021, the MHW became coarser from medium to coarse sand but returned to medium sand in 2022. Carbonate content ranged between 48-62% from 2019-2022.

Figure 7. Mean grain size (φ) for the samples obtained on the high (H), mid (M), and low (L) beach profile for each location.



Source: the authors

Figure 8: Sorting (standard deviation) for the samples obtained on the high (H), mid (M), and low (L) beach profile for each location.



Source: the authors

PREDICTED BEACH SLOPE

Using the median grain size from the MHW (low) sediment samples, the predicted slope was calculated for protected, moderately protected, and exposed beach scenarios. The predicted slopes were then compared with the measured foreshore slopes (Table 2). The steepest slopes were predicted for protected beaches and the most gentle slopes were predicted for exposed beaches. For all locations, the protected beach equation most closely matched the measured slopes.

Table 2: Measured beach slope compared to predicted slopes (best fit and measured slopes shown in bold).

Location	*R13A*				*R21*			
Year	2019	2020	2021	2022	2019	2020	2021	2022
Median Grain Size (mm)	0.48	0.23	0.26	0.23	0.24	0.32	0.30	0.47
Measured	**1:6**	**1:14**	**1:18**	**1:9**	**1:8**	**1:7**	**1:9**	**1:9**
Protected	**1:7**	**1:16**	**1:14**	**1:16**	**1:15**	**1:11**	**1:12**	**1:7**
Moderately Protected	1:8	1:30	1:24	1:30	1:27	1:16	1:18	1:8
Exposed	1:15	1:59	1:47	1:59	1:55	1:32	1:36	1:16
Location	*R27*				*R34*			
Year	2019	2020	2021	2022	2019	2020	2021	2022
Median Grain Size (mm)	0.25	0.24	0.24	0.24	0.22	0.24	0.23	0.23
Measured	**1:9**	**1:8**	**1:11**	**1:11**	**1:9**	**1:7**	**1:15**	**1:13**
Protected	**1:14**	**1:15**	**1:15**	**1:15**	**1:16**	**1:15**	**1:16**	**1:6**
Moderately Protected	1:25	1:27	1:27	1:27	1:32	1:27	1:30	1:30
Exposed	1:51	1:55	1:55	1:55	1:64	1:55	1:59	1:59
Location	*R51*							
Year	2019	2020	2021	2022				
Median Grain Size (mm)	0.27	0.31	0.33	0.24				
Measured	**1:12**	**1:13**	**1:14**	**1:17**				
Protected	**1:13**	**1:11**	**1:10**	**1:15**				
Moderately Protected	1:22	1:17	1:15	1:27				
Exposed	1:44	1:34	1:30	1:55				

Source: the authors

DISCUSSION

Variability of sediment texture was not always associated with changes in the foreshore slope (e.g., the expectation that coarser sediment results in steeper slopes and finer sediment results in gentler slopes). In 2019, annual placement of BUDM resulted in the coarsest sediment at R13A and a corresponding steep slope (1:6) compared to other locations of shore protection projects that had finer and better sorted sediment. Subsequently, sediment consisted of moderately to moderately well sorted medium sand a gently sloping beach from 2020-2021. However, in 2022 the foreshore was again steep with a 1:9 slope, but the sediment remained moderately to moderately well sorted medium sand. So although larger grain size was associated with a steep slope at R13A in 2019, the post-nourishment equilibration process likely contributed to the steeper slope measured in 2022 despite no change in sediment properties (Willson et al. 2017).

Slopes did become gentler after nourishment at R27 and R34. In contrast, steep slopes (1:7 to 1:9) were measured at R21 where only dune restoration was completed compared to the other nourished transects. The steeper slope measured at R21 did not correspond to larger grain size. The lowest carbonate content was measured at R21 after placement of upland mine material in 2020 and 2022 at the dune toe with 20% and 29%, respectively, indicative of the higher siliciclastic content from upland mines (despite a high carbonate content found at the MWH with 93%). Rather than the sediment properties, it is likely that adjacent structures could be influencing the slope. R21 is located just updrift of the Jupiter Reef Club (approximately 40 meters) that is armored with a seawall located seaward of the general shoreline and therefore wave exposed. It is possible that the seawall is altering the hydrodynamic conditions and influencing sediment transport resulting in steeper slopes on the adjacent beaches (Balaji et al. 2017). Steeper slopes were also measured at R13A that is in close proximity to the south jetty of the Jupiter inlet (~260 meters downdrift).

The largest variability in mean grain size and sorting between 2020 and 2022 was observed at R34, with sediment ranging from poorly to moderately well sorted coarse to medium sand. Even after placement of the offshore material, R34 continued to show the most variability in sediment. This pattern was also observed in Brown and Briggs (2020) which could be the result of a nearby marine life facility using water intake pipe that extends across the swash zone. The least variability in sediment characteristics and beach slope was at the non-nourished R51 location. Sediment characteristics at the beaches managed with offshore or inlet sources (i.e., at R13A, R27, and R34) were similar to R51 where the mean grain size generally ranged between 1.00-1.63 φ. The greatest difference in sediment properties and slope compared with the non-nourished beach was at the site with upland mine sediment placed at the dune toe at R21. However again, it is not likely that the sediment source was the significant driver in variability at R21 but rather the complicated hydrodynamics associated with the adjacent wave exposed seawall. Incidentally, this location was also the site of the largest morphologic changes during the 2020 hurricane season (Briggs et al. 2021), also suggesting that the seawall causes complicated nearshore hydrodynamics. In summary, the various borrow sources used for beach and dune nourishment are similar to the non-nourished beach properties and result in more natural, gentle slopes.

In addition to the apparent influence of beach proximity to hard structures on morphology and sedimentology, the geographic proximity to a large archipelago may also have significant influence on the local beach morphology. Brown and Briggs (2020) determined that the protected beach equation from McFall (2019) provided estimates most similar to the measured slope at all locations in 2019. Slopes measured in 2020-2022 were also closest to the predictions for protected beach conditions. Therefore, the apparent reduced fetch from the nearby Bahamian archipelago contributes to the coasts' protected beach state and may be a major influence on overall morphology and slope.

SUMMARY

Sedimentology and morphology of nourished and non-nourished barrier island beaches in northern Palm Beach County, Florida, USA, were analyzed from 2020-2022 to provide a brief update from beach conditions in 2019 published by Brown & Briggs (2020). Although sediment varied alongshore and cross-shore, sediment on nourished beaches were similar to the non-nourished location with a few instances of coarser or more poorly sorted material at some locations. The average mean grain size of sediment near the shoreline in northern PBC over the four-year study period was 0.40 mm. The McFall predictive equation for a protected beach produced values most similar to the measured slopes at all locations. Even where sediment varied, the protected beach predictive equation was the best fit and likely a result of reduced fetch from the nearby large Bahamian archipelago. In addition, proximity to hard structures is likely a major contributor to the spatiotemporal variability in morphology and sedimentology and their influence on local hydrodynamics should be evaluated further. In summary, the erosion mitigation strategy of beach nourishment using BUDM and offshore borrow sources are compatible with the natural beaches in northern Palm Beach County, FL.

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