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The Role of Storm-Driven Seaward Sediment Flux in Coastal Barrier Dynamics Is an Enduring Puzzle

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Key Points:

- Sediment transport seaward during storms remains largely overlooked in coastal research
- Seaward outwash may shift more sediment by volume than onshore-forcing processes of beach and dune erosion
- The complex relationship between storm-driven seaward transport and barrier recovery opens exciting questions regarding barrier evolution

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Abstract Coastal barrier systems are low-lying environments that bear the brunt of storm impacts, with cumulative and complex consequences for barrier evolution. Most studies of barrier responses to storms examine what happens when water and sediment get driven landward across a barrier from its ocean side. Sherwood et al. (2023, https://doi.org/10.1029/2022jf006934) investigate the effects of overland flow and sediment transport forced across a barrier in the opposite direction—from its sheltered side, seaward. Using high-resolution imagery of a barrier island observed before and after a hurricane, Sherwood et al. (2023, https://doi.org/10.1029/2022jf006934) show that "outwash" flow across the barrier shifted several times more sediment by volume than is typically reported for beach and dune erosion from onshore forcing. Their findings are remarkable because they are not exceptional: a related survey of barriers along the Atlantic and Gulf Coasts of the USA observed patterns of outwash morphology essentially everywhere. Insights into outwash morphology open exciting questions regarding the overlooked role of storm-driven seaward sediment transport in barrier dynamics, with important implications for post-storm barrier recovery and barrier evolution over decades to centuries.

Plain Language Summary Coastal barrier systems—beaches backed by dunes, marshes, and often a lagoon or sound—offer natural protection to coastal floodplains by absorbing some of the physical impacts of storms, including hurricanes. Most studies of storm impacts on coastal barriers investigate changes that occur when a storm drives water and sediment landward, over a barrier from its ocean-facing side. But storms also drive sediment-laden flows in the opposite direction: over the back of a barrier from its more sheltered side, toward the ocean. Here, I highlight work by Sherwood et al. (2023, https://doi.org/10.1029/2022jf006934) that details extensive patterns of erosion and accretion from "outwash" flow seaward over a barrier during a hurricane. Added up over time, sediment shifting landward and seaward across a barrier shapes the barrier landscape and affects how the barrier may respond to future storm impacts. Sherwood et al. (2023, https://doi.org/10.1029/2022jf006934) offer findings with important implications for understanding how coastal barriers evolve in space and time, and address a question that is fundamental to many geomorphic systems: when a large volume of sediment moves during an extreme weather event, where does it all go?

Natural barrier systems at the seaward edge of low-lying coastal environments owe much of their geomorphology to storm events. Determining the volume of barrier sediment that moves with the passage of a storm, the pathways that parcels of sediment trace from one place to another, and at what rates and by which physical processes, collectively comprise a perennial puzzle in barrier research of the past six decades (Donnelly et al., 2006). Explaining how a barrier system metabolizes storm impacts across a hierarchy of spatial and temporal scales (cf. Werner, 2003) is itself a critical piece of a bigger unfinished puzzle: to formalize, and generalize, a complete sediment budget for barrier systems. Sediment budgets are a fundament of geomorphology. To understand the sediment budget is to understand the system, goes the rationale—and thus understand how the system will evolve into the future, maybe with enough insight to manage the trajectory of that evolution. So when new research details a storm-driven process of sediment transport that is otherwise missing from barrier sediment budgets, coastal scientists in their reading chairs sit up a little straighter.

A coastal barrier is a ridge of sediment oriented with its face to the prevailing weather. Storms punch gaps in the barrier crest. Where a combination of surge, waves, and tide is able to exceed the height of the barrier, shallow overland flow will push over the crest and across the barrier. These flows, in the landward direction, are called overwash, and the sedimentary deposits that overwash leaves behind are called washover. Overwash is a vital disturbance regime for barrier ecosystems (Zinnert et al., 2017) and constitutes a fundamental mechanism by

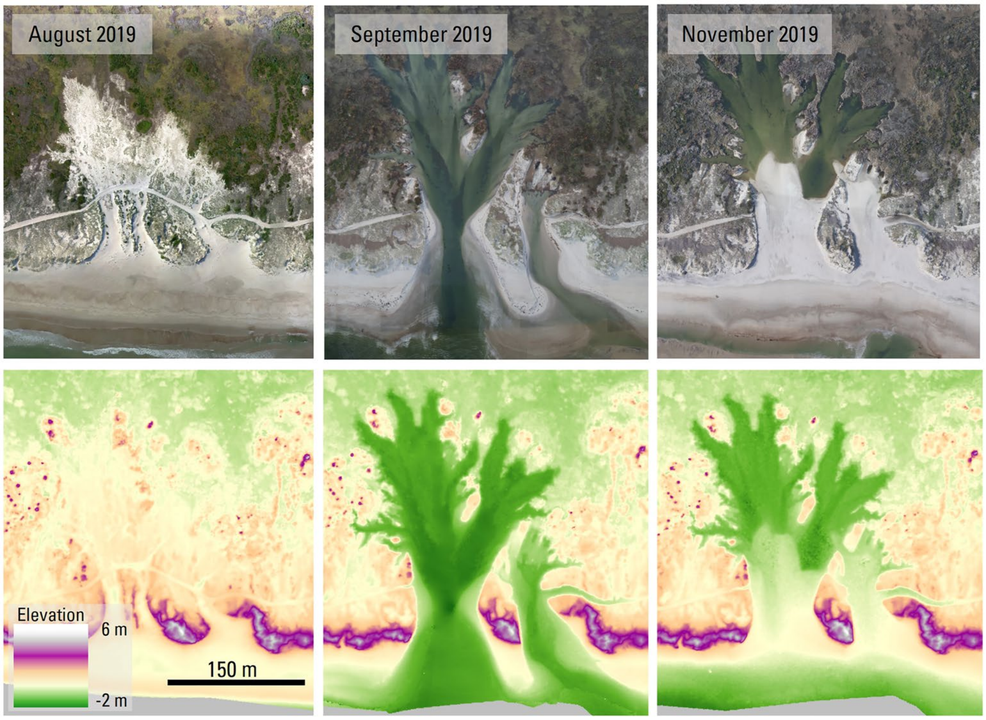

Figure 1. Orthomosaics (top row) and digital elevation models (bottom row) of an outwash site on North Core Banks, North Carolina, USA, before (left), immediately after (middle), and approximately 3 months after (right) the passage of Hurricane Dorian in 2019. Co-located with an existing washover site (left), outwash flow driven by the hurricane eroded material from the barrier core and transported it seaward (middle). Fresh sand in the outwash network (right)—indicative of volumetric recovery—was evident many weeks later, following a winter nor'easter. Figure courtesy of Christopher Sherwood, Jin-Si Over, and coauthors of Sherwood et al. (2023).

which natural barrier systems maintain their elevation and width relative to sea level (Donnelly et al., 2006; FitzGerald et al., 2008; Leatherman, 1979). While most studies of storm impacts on coastal barriers consider overland flow, sediment transport, and deposition in the landward direction (Donnelly et al., 2006), only a handful of studies since the late 1960s have considered the counter-phenomena, in the seaward direction (Over et al., 2021).

New work published in this journal by Sherwood et al. (2023) presents the first definitive, systematic examination of "outwash" and "washout": storm-driven, seaward-directed morphodynamics that excavate high quantities of sediment from the barrier core and deliver it to the foreshore and nearshore (Figure 1). Their findings suggest that outwash and washover are ubiquitous, frequent, and voluminous enough to constitute a sizable process loop in the sediment budget for barrier systems. But the authors are also candid about the point at which the thread of their inquiry disappears into the surf, where coastal sediment budgets are notoriously leaky. The volume of sediment transported seaward for which Sherwood et al. (2023) cannot account is intriguing: its loss from, or eventual restoration to, the barrier has implications for post-storm barrier recovery and, iterated over far longer time scales, for barrier evolution.

Cyclonic storms create conditions conducive to outwash and washout. For example, because cyclones in the northern hemisphere rotate anti-clockwise, an Atlantic hurricane that tracks straight into a coastline will propel water onshore to the right of the eye, and offshore to the left of it. For barriers backed by a lagoon or sound, offshore forcing may drive water over the inland side of the barrier, toward the ocean. If a cyclone crosses a coastline squarely, the spatial extent of outwash and washout morphology will tend to scale with the radius of the storm. But a cyclone that tracks along a coastline can churn outwash and washout in its wake over significantly greater distances (Over et al., 2021). Sherwood et al. (2023) focus on an alongshore array of 86 outwash channels incised into North Core Banks, North Carolina, USA, by Hurricane Dorian, in 2019. As the hurricane traveled northeast up the barrier chain of the Outer Banks, onshore winds forced additional water into the broad basin of Pamlico Sound. Offshore winds then sloshed that water back out, over the back-barrier side of North Core Banks and neighboring Ocracoke Island. Outwash downcut through the barrier topography and deposited tongues of washout to the foreshore. This paired morphology of seaward-oriented dissection and deposition, reminiscent of incised valleys and alluvial fans along a mountain front (Bull, 1962; Denny, 1965; Lazarus, 2016), is what jumped out at Sherwood et al. (2023) from high-resolution aerial imagery collected before and after the hurricane (Figure 1).

Outwash processes are not the only mechanism for seaward sediment transport in barrier environments. Beach and dune erosion by wave collision during storms lowers the ocean-side barrier profile and drags sediment into the surf zone. On sandy barriers, offshore winds send sand by aeolian transport from the beach and dunes into the sea. Ebb flows through tidal inlets build ocean-side deltas that store huge volumes of sediment within littoral transport pathways. But even Sherwood et al. (2023) seem surprised that the volume of seaward sediment flux from outwash they calculate is "five to 10 times larger than most reported volume losses from beaches and dunes during ocean-side storms." Moreover, along the Atlantic and Gulf barriers of the USA, scars of outwash morphology are everywhere: Over et al. (2021) estimate that an outwash event likely occurs somewhere on US barrier coastlines at least once a year. Outwash clearly transfers a lot of sediment, yet Sherwood et al. (2023) are reticent, pointing out the many unknowns regarding "what long-term role [outwash and washout] play in barrier morphodynamics" relative to other processes. Those unknowns set up exciting, open questions about the long-term net effects of storm-driven seaward sediment transport more generally in barrier systems.

For example, the picture of barrier evolution that emerges with the incorporation of storm-driven seaward forcing is subtly more circulatory than conceptual models usually convey. Dillon (1970) described a barrier "essentially rolling over itself" in its movement landward. Swift (1975) explained how a "barrier superstructure may retreat in cyclic, tank-tread fashion, by a process of storm washover of sand, its burial, and re-emergence at the upper shoreface." These results from Sherwood et al. (2023) are a reminder that even in the classical "tank tread" model of barrier transgression, the track sometimes loses grip: the barrier spews material behind itself as it rumbles forward. Offshore aeolian transport, ebb-tidal inlets, dune collision, and washout all represent that slippery spinning of the tread seaward. By supplying material to the foreshore, do these processes of seaward transport collectively feed a pathway of recycled sediment that helps sustain the landward migration of the barrier system overall? Or, in the context of other environmental forcing, is there a threshold in barrier volume at which these natural seaward fluxes become a geomorphic liability?

Hewing close to what they can best quantify, Sherwood et al. (2023) frame their measurements in terms of "volumetric loss" from the barrier core. The relative balance of transience and permanence in that loss is unclear. "The fate of the sand eroded from the outwash channels is unknown," Sherwood et al. (2023) concede, but they tender some possibilities. Some sand might end up sequestered on the lower shoreface and effectively out of reach for fair-weather swell. Most of it is likely "deposited in relatively shallow water" and therefore "available for transport back to shore." The authors illustrate this likelihood with evidence of infilling and nascent volume recovery in the outwash channels within a couple of months of Hurricane Dorian (Figure 1). Elsewhere, spatial patterns of beach erosion and accretion after a storm have been shown to mirror each other with astonishing symmetry for many tens of kilometers alongshore (List et al., 2006). And some sand, Sherwood et al. (2023) note, will be "swept away by alongshore transport." But transport alongshore does not necessarily mean that any sand entrained is lost from the sediment budget: "shoreline interconnectivity" alongshore is a vital means by which barriers can support their own volumetric repair and maintenance under transgression (Ashton & Lorenzo-Trueba, 2018). With only so much sand available the nearshore and foreshore, sediment transport alongshore might slow cross-shore recovery, but gradients in wave-driven alongshore sediment flux are a powerful driver of barrier dynamics over long time scales (Ashton & Murray, 2006a, 2006b; Lazarus et al., 2011). Wherever that outwashed sand goes, Sherwood et al. (2023) write, "has implications for the morphological evolution of the entire barrier chain."

Sherwood et al. (2014)—same Sherwood, different *alia*—approached another expression of this complex relationship between outwash morphology and post-storm barrier recovery a decade ago, when measuring and modeling seaward sediment transport across the Chandeleurs with Hurricane Isaac, in 2012. In that study, Sherwood et al. (2014) remarked that Kahn (1986) had observed "how storm surge ebb has resulted in subtidal sand deposits on the ocean side of the Chandeleur Islands and argued that the availability of this sand supply in the nearshore speeds post-storm morphologic recovery." Whether and how washout might recirculate into the processes of barrier recovery at different time scales needs exploring. On North Core Banks, Sherwood et al. (2023) are understandably circumspect about what opposing seaward and landward fluxes on the time scale of a single hurricane event may mean for barrier dynamics over many decades to centuries. Sherwood et al. (2014) demonstrated that outwash-like flow and resulting sediment transport can be rendered in a fully hydrodynamic numerical model for a localized site on a natural barrier at the event scale. Integrating outwash morphodynamics into existing numerical models of barrier evolution (Lorenzo-Trueba & Ashton, 2014; Lorenzo-Trueba & Mariotti, 2017; Mariotti, 2021; Nienhuis & Lorenzo-Trueba, 2019) could yield informative comparisons of barrier states and behaviors with and without storm-driven, seaward-directed processes, particularly as they pertain to time scales of potential barrier drowning.

All of these process-based models, however, operate in domains without humans as prolific agents of coastal geomorphic change. Recently, I pored over hundreds of emergency response images from storm strikes along the Atlantic and Gulf Coasts of the USA (Goldstein et al., 2021). While some images chance upon beautiful and unfamiliar geomorphic features in settings without any sign of human presence, most reflect coastal barriers in varying degrees of suburbanization. As I read Sherwood et al. (2023) describe outwash flow across a natural barrier, I kept imagining a different case: outwash flow cresting bayside bulkheads (Gittman et al., 2014, 2015; Polk & Eulie, 2018; Smith et al., 2017) and coursing over lawns, through swimming pools, around houses, under SUVs, and down streets on its way to the beach. What manner of stuff does outwash across an urbanized barrier excavate, entrain, and deliver to the swash zone (cf. McNamara et al., 2023)? I also thought of a related anthropogenic process of seaward sediment transport: one affected by the road crews who clean up during and after big weather events, plowing unquantified volumes of sediment off barrier roads and into foredunes (e.g., Lazarus & Goldstein, 2019; Nordstrom, 2004). Natural seaward sediment transport might not necessarily affect a permanent volumetric loss from the barrier core, but its mechanized counterpart does. When sediment from the barrier core is plowed seaward into an artificial dune to block further overwash and washover, over time that barrier can only narrow and lose elevation relative to sea level. Sherwood et al. (2023) describe the outwash process as a setback for barrier transgression; the purpose of mechanized seaward sediment transport is to arrest transgression altogether.

There is graciousness in the way Sherwood et al. (2023) use such an authoritative study to invite further work. The authors do not put forward their own numerical modeling exercise but, like a kit from a hobby shop, all the necessary elements are there, laid out with instructions. Storm-driven, seaward-directed transport—natural and mechanized, through non-built and built environments—is indeed a missing part of paradigmatic models of coastal barrier dynamics. Innovation in high-frequency, high-resolution remote sensing will make outwash morphology only more visible and measurable. Innovation in modeling approaches should be close behind.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

No datasets were created or used for this article.

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