A conceptual beachhead: “Beaches and dunes of human-altered coasts” by Karl F. Nordstrom (1994)

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Abstract
Approaching 30 years since its publication in Progress in Physical Geography, Nordstrom’s work from 1994 reads like an uncannily current synopsis of grand challenges in interdisciplinary coastal science. The article is a playbook of testable hypotheses for emerging and future empirical coastal research.

Keywords
Coastal systems, built environment, anthropogenic controls

I Introduction
Published in Progress in Physical Geography nearly three decades ago, “Beaches and dunes of human-altered coasts” by Karl Nordstrom (Nordstrom, 1994a), has proven remarkably prescient. Hide all mentions of dates, and the work reads like a current prospectus of emerging topics in interdisciplinary coastal science. The scale, dominance, and rapid sprawl of human impacts on physical coastal environments had some traction in the 1990s as a worrisome societal problem (Pilkey and Neal, 1984), but academic circles tended to badge the topic as applied science—and so dismiss it—there but for a better engineering consultant. What distinguishes Nordstrom’s contribution, even now, is his clear conception of human-altered coasts as dynamic environments unto themselves, where expressions of physical phenomena warranted fundamental geomorphic research.

II Coastal neogeomorphology
Nordstrom’s essential observation was that human-altered coastlines are dynamically distinct from their non-altered counterparts—and by extension, need to be treated that way. Conversion of coastal environments from non-built to built settings changes “the shape, size, location, internal characteristics, and mobility of the landforms” (Nordstrom, 1994a: 500), which in turn affects “mechanisms of change, freedom of movement, locations of sources and sinks for sediment,…and spatial and temporal scales of landform evolution” (Nordstrom, 1994a: 497). To have any hope of understanding patterns and trajectories of physical change along human-altered coasts—let alone planning for and managing them—Nordstrom argued that coastal research must address that dynamical divergence, turning “the geomorphic significance of human agency” into “an integral component of landscape evolution” rather than “an aberration” (Nordstrom, 1994a: 498).

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The understated tone of Nordstrom’s exposition belies a radically alternative vantage for coastal physical geography. Nordstrom took pains to situate his review relative to the vast literatures of coastal engineering, planning, and environmental management. He pointed out the holistic utility of those literatures as sources of “valuable insight to the human processes operative in developed coastal systems and the way shorelines have been modified from natural conditions” (Nordstrom, 1994a: 498). But the kind of research he was advocating was not engineering, or planning, or management—though it had bearing on all of those fields. Nordstrom was effectively describing the coastal built environment as its own type of landscape system. A developed barrier island was not a “natural” barrier with buildings sprinkled atop it, but something apart: the physical setting and basic characteristics of a barrier island, with the alien states and behaviors of an environment—terrain and ecology—transformed in terms of earth-mass moved annually “to suit human needs” (Nordstrom, 1994a: 497).

By coincidence, just a few months before Nordstrom’s article appeared in Progress in Physical Geography, Roger LeB. Hooke made the September 1994 cover of GSA Today with a feature highlighting the importance—quantified in terms of earth-mass moved annually—of humans as agents of geomorphic change (Hooke, 1994). The underlying idea is an old one: look to George Perkins Marsh (1865, 1882) and Robert Lionel Sherlock (1922), for example (Butler 2018; Ellis, 2017). Israeli geomorphologist Dov Nir (1983) wrote an “introduction to anthropic geomorphology” that was regarded as “refreshing and stimulating” in its perspective, if underworked in its scholarship (Butzer, 1984). Phillips (1991) mused on “the human role in earth surface systems,” citing one of Nordstrom’s early anthropic coastal papers (Nordstrom, 1987). Drawn separately into the same zeitgeist, Nordstrom (1994a) and Hooke (1994) became instrumental in placing human agency in the current frame of physical geography.

Within that frame, the fields of coastal and terrestrial geomorphology still tend to operate in independent spheres. One of the first readers to connect the dots between Nordstrom and Hooke was Peter Haff, who referred to their works together in his coinage and description of “neogeomorphology” as the defining geomorphic paradigm of the Anthropocene (Haff, 2002, 2003). Haff emphasized that human earth-moving activities (e.g., agriculture, road building, residential and commercial construction, mining) collectively comprise a novel dynamics of sediment transport—one that not only shifts more material of the Earth’s surface than all natural processes combined (Haff, 2003; Hooke, 1994, 2000), but does so in evolutionarily unprecedented ways, via purposeful technological mechanisms (Haff, 2010, 2012). Where Hooke focused on the outsized scale of human earth-moving activities relative to natural geomorphic processes, Nordstrom and Haff, respectively, went further, arguing that the physical evolution of modern and future landscapes, coastal and otherwise, cannot be understood without accounting for human agency. A world dominated by the human built environment limits the roles and bends the “classical” rules of natural environmental processes. “The branch of geomorphology that attempts to identify the principles of landscape change as driven by the Anthropic Force, and to predict or influence that change, is distinct from classical geomorphology,” Haff wrote. Naming this branch “neogeomorphology” emphasizes its focus on modern (and, by extension, future) earth surface phenomena” (Haff, 2003: 15).

Nordstrom and Hooke appear to have been about 15 years early with their ideas, and Haff about 10. A bibliometric calculation of “delayed recognition” (Goldstein, 2017), using Scopus citation data for 1994–2020, suggests that the “awakening” year when citations for Nordstrom (1994a) began to pick up was 2010; the “awakening” for Hooke (1994) was 2008. These dates—which are indicative, not golden spikes—broadly coincide with a multidisciplinary groundswell of interest in coupled human–natural systems and social–ecological systems (Ellis and Ramankutty, 2008; Folke, 2006; Liu et al., 2007; Ostrom, 2009; Werner and McNamara, 2007). Nordstrom and Haff presaged for geomorphology the door that Ellis and Ramankutty (2008) opened in ecology, with the concept of “anthropogenic biomes” or “anthromes.” Just as physical geography tends to turn its attention to settings absent of humans, “the biosphere has long been depicted as being composed
III Topical resonance

The document of Nordstrom (1994a) includes no figures, no tables, no reported rates, no quantitative meta-analysis. A reader interested in more technical specifics can pursue the references provided. The majority of those references are, or hinge on, case studies. But Nordstrom’s synthesis of them conveys a conviction that the phenomena he describes are generic, varying in local detail but otherwise evident on coastlines around the world. The past decade has been one of quantitative catch-up with Nordstrom (1994a), across ever-larger spatial scales and weightier ramifications.

3.1 Beach nourishment

Take beach nourishment, for example. The term refers to a coastal engineering process in which sand is deliberately deposited on an actively eroding beach as a form of hazard mitigation (NRC, 1995). Nordstrom refers to beach nourishment as the shoreline-protection strategy “that is currently in vogue” (Nordstrom, 1994a: 499), and discusses its atypical geomorphic characteristics, from the hard chine of its geometry (a wide, over-steepened upper beach profile that rapidly dissipates) to the locally incompatible sediments (too fine, too coarse, too shelly) that often comprise the fill. In the 1990s, the application was booming. Nordstrom cites a preliminary tally by Pilkey and Clayton (1987) that “over 90 beaches in the USA have been nourished in more than 200 separate operations” (Nordstrom, 1994a: 501). The long-running database maintained by the Program for the Study of Developed Shorelines (of which Orrin Pilkey was the founding director) now lists over 2000 episodes in the USA since 1923, in every ocean-facing state but Oregon (and some in the Great Lakes), totaling more than a billion cubic meters of sand and an inflation-adjusted price-tag of over $10.8 billion (PSDS, 2021). “Beach nourishment is now used nearly routinely throughout the world,” Nordstrom wrote (Nordstrom 1994a: 501), citing Swart (1991) and Davison et al. (1992). The caveat of that sentence has since been obviated. Europe has lost count of its collective episodes: the last attempt at an overview of country-specific nourishment activities was published 20 years ago (Hanson et al., 2002).

An unintended consequence of so much beach nourishment in the USA is that so much intentional deposition may have reversed trends in shoreline change at the continental scale. Focusing on the northeastern Atlantic coast from Virginia to Maine, Hapke et al. (2013) showed that over large spatial extents alongshore, mean rates of long-term (centennial) versus short-term (multi-decadal) shoreline change have switched from negative to positive—from eroding to accreting. Their conclusion was that “even modest amounts of development influence the rates of change” (Hapke et al., 2013: 160), such that “any natural signal appears likely to be masked by activities associated with human development in most areas except those that have sparse levels of development” (Hapke et al., 2013: 169). The only reaches in which “the shoreline respond[s] as expected with respect to the coastal geomorphology” are the empty ones (Hapke et al., 2013: 169). A colleague and I extended this inquiry to the entire US Eastern Seaboard, but divided the shoreline records into two periods: approximately before and after the onset of widespread beach nourishment (Armstrong and Lazarus, 2019). We found an even more pronounced reversal in shoreline change trends—and a spatial pattern that suggests there is little of the US Atlantic shoreline that beach nourishment has not touched, directly or by diffusion. The influx of...
nourishment sediment is perhaps so strong that “background” rates of shoreline change may be impossible to discern given available records of shoreline position. Moreover, such ubiquitous and repeated anthropic geomorphic disturbance has deleterious effects on beach and benthic fauna—yet a lack of baseline assessment and monitoring means the full extent of those effects remains unknown (Peterson and Bishop, 2005).

3.2 Modeling

Although Nordstrom (1994a) included a section on “models of evolution of developed coasts,” he invoked “models” in a general sense. He described approaches to conceptual models that could explore how developed coasts change over time, but did not present a complete example. Rather, his own conceptual model of developed coastlines as dynamical systems is suffused throughout the article, with its main aspects discernible from the section headings: “large-scale landscape conversions”; “creating, re-shaping or eliminating landforms to suit human needs”; “effects of protection structures and buildings; distinguishing natural from human-altered landforms”; “effects of storms and climate change on the evolution of developed coasts.”

To date, the only dynamical model that explores the holistic evolution of a developed coastline—a sandy barrier system, like many of Nordstrom’s examples—is a numerical model by McNamara and Werner (2008a, 2008b) that couples natural physical processes and human activities. While other numerical coupled human–coastal models have been presented since, those have tended to isolate the dynamics of a specific activity or element, such as beach nourishment (Gopalakrishnan et al., 2017; Jin et al., 2013; Lazarus et al., 2011; McNamara et al., 2011; Murray et al., 2013; Williams et al., 2013) or post-storm dune reconstruction (Magliocca et al., 2011) or beachfront real-estate markets (McNamara and Keeler, 2013; McNamara et al., 2015). Still other modelling exercises might use a hydrodynamically detailed numerical model to investigate surge depths (Brown et al., 2007) or flow paths through a built environment (Smalley and Irish, 2017), or to examine the damage effects of different kinds of storm impacts on buildings (Van Verseveld et al., 2015). A similar approach can be taken for tsunamis (Bricker et al., 2015; Park et al., 2013). But these types of study, focused on hazard impact, do not address the developed coast as a coupled dynamical system.

Consider, then, the breadth and depth of processes in McNamara and Werner (2008a). The physical barrier island component of the model includes: a nonerodible continental shelf; a shoreface that can vary in slope; a nearshore sandbar reservoir from which sand can shift alongshore or cross-shore; geometrically simplified triangular dunes that can migrate, grow vegetation (which affects sediment flux across the dune), get destroyed by storm events, and recover in the intervals between storms; storm-driven surge, shoreface erosion, washover, and cross-shore sediment redistribution (which adjusts barrier height and width); wave-driven alongshore sediment transport, with gradients created by the relative angle between the shoreline and incident waves; storm events, treated as surge, that vary over time in frequency and magnitude; and sea-level rise. McNamara and Werner (2008b) presents an “enhanced version” of the barrier model with additional nearshore processes that address inlet initiation, migration, and formation of an ebb-tidal delta. Processes in the model (with and without inlets) operate within one of two different time scales: a storm time scale of hours to days, which governs surge, washover, dune destruction, associated redistribution of sediment stores, and rapid geometric adjustment of the barrier cross-section; and a longer “interstorm” time scale, on the order of years, during which dunes grow and vegetate, and alongshore sediment transport redistributes sand along the barrier shoreface, driving more gradual adjustment to barrier geometry.

And then there are the human components of the coupled model, which involves four different kinds of complex adaptive agents. “Economic agents” deal in beachfront hotel real-estate as either developers or owners, and tourists visit the resulting “resorts” that arise. “Policy agents” govern coastal-management actions. The “enhanced” model, which for empirical comparison simulates the evolution of Ocean City, Maryland, includes jetty emplacement as an additional coastal-management policy.) Hotel developers,
owners, and tourists respond to the emergent dynamics of a modeled economic market. Developers assess property values and weigh expected revenues against costs to decide whether or not to build a hotel, and if so, how big to build it (by number of rooms). Owners assess and adjust room prices to maximize revenue. Tourists choose where to book rooms on the basis of several factors, weighted differently among individual agents, including their familiarity with the beach (which can be influenced by familiarity among their vacation-going neighbors), the total expense required to travel there (as a function of distance) plus the price of the hotel room, and how wide the local beach is. Policy agents weigh the revenue from property and sales taxes (driven by the hotel stock and its performance) minus the cost of a shoreline-protection project (beach nourishment and dune building) of the size required at their beach. If the net benefit of an intervention outweighs the net benefit of waiting, then the shoreline-protection project goes ahead. Storms greater than a certain threshold magnitude destroy resort infrastructure, as does chronic erosion that reaches far enough inland to impinge upon development. Insurance against storm damage, accounted for by the developers and hotel owners, covers damages up to an extent. At some critical point, the market determines that the costs of development and hotel ownership are too high. Protective interventions end, tourists drift elsewhere, and the resort— one of many scattered along the length of the barrier—crashes. (In the model, a resort destroyed by a storm is not repaired, receives no further investment, and, for all intents and purposes, is eventually resorbed into the barrier.) Such boom-and-bust cycles of resort development move along the barrier in space and over time.

Although McNamara and Werner (2008a, 2008b) do not cite Nordstrom (1994), together the works are highly complementary: the former is like a dynamical animation of certain descriptions sketched out in the latter. Both discuss the transformation of barrier coasts from natural, autogenic systems governed by frequent, low-magnitude geomorphic changes, to human-dominated systems typified by infrequent, high-magnitude, destructive hazard events. The effective lever of this transformation is hazard defense, which filters out minor events at the expense of major ones, and, paradoxically, tends to encourage infrastructure growth in its shelter (Burby, 2006; McNamara and Werner, 2008a; Werner and McNamara, 2007). Nordstrom and McNamara and Werner discuss the emergence of cyclic changes on human-altered coastlines across a hierarchy of time scales, from seasonal beach grading to multi-annual periods between major storm events. McNamara and Werner (2008a, 2008b) extend the dynamics of their model system to logical exhaustion over very long time scales to demonstrate the possibility of cyclical growth and decline in coastal resort infrastructure. Nordstrom speculated that models with an “active human-input approach, which considers human action as endogenic rather than exogenic,” citing Phillips (1991), “is more realistic for intensively developed areas and will have increased usefulness in the future” (Nordstrom, 1994a: 508). Decades later, the “increased usefulness” of such models is perhaps the insight and exploration they enable into the possible dynamics that emerge in even deliberately simplified abstractions of coastal coupled systems—but such models, whether conceptual or numerical, remain the exception (Jackson and Nordstrom, 2020; Lazarus et al., 2016).

3.3 Empiricism

Nodding to parallel work he published the same year (Nordstrom, 1994b), Nordstrom lists three approaches to research into “developed coasts…that may determine, a priori, the extent to which human alteration will be considered an aberration or an integral part of the coastal system” (Nordstrom, 1994a: 508). One approach treats humans as endogenous to the coastal system; its opposite assumes that “the kind of shoreline change that occurred in the recent past will continue unabated by local actions.” The third approach, which “compares and contrasts a developed area with an undeveloped area that is assumed to have the same process controls,” is the one driving a new wave of empirical coastal inquiry.

One example, prominent for its spatially extended scale, is the study by Hapke et al. (2013) that quantified rates of shoreline change along a gradient of coastal development, from “sparse” to “urban,” and showed starkly contrasting geomorphological behaviors between those endmembers. Hapke et al. (2013)
pointed to a literature of compare-and-contrast case studies regarding the effects of seawalls on shoreline variability, of which an early but overlooked example is a report by Morton and Paine (1984), who measured intrusion lengths of washover deposition and cross-shore changes in the vegetation line along “natural” versus “developed” beaches on Galveston Island, Texas, after a hurricane. A separate body of compare-and-contrast studies is growing around another topic raised by Nordstrom (1994a) regarding urbanized coastal dune fields, quantifying the aeolian effects of encroachment by the built environment into non-built space (García-Romero et al., 2019; Jackson and Nordstrom, 2011; Smith et al., 2017).

Yet, another topic of comparative study that Nordstrom (1994a) was among the first to describe—and to collate the slim literature of other descriptions that existed (Bush, 1991; Hall and Halsey, 1991)—is the phenomenon of washover onto low-lying coastal streets and roads. Storm-driven sediment deposition into roadways is both common and strange. Common, in that its occurrence is ubiquitous, just as in non-built settings. Strange, in that deposits tend to be shaped by the “fabric” of the built environment, raveling down streets and between (or under, or inside) buildings—but then cleared so rapidly by road crews with earth-moving equipment that quantitative observations of deposit morphometry remain rare, relative to their non-built counterparts (Lazarus et al., 2021; Nelson and Leclair, 2006; Rogers et al., 2015). Much like Morton and Paine (1984) but with more precise tools, Rogers et al. (2015) used lidar to quantify morphometric characteristics (cross-shore volume, length of inland extent) of washover into non-built and built sections of the New Jersey coastline after Hurricane Sandy, in 2012. They presented their results as scaling relationships to show the relative, systematic effects of anthropogenic controls on geomorphic expression. Colleagues and I recently extended this analytical avenue to more locations and different hurricanes, using post-storm aerial imagery to construct additional comparative scaling relationships for morphometric characteristics of washover deposits in non-built versus built settings (Lazarus et al., 2021).

Such empirical scaling relationships matter to the application of numerical models as tools for predicting geomorphological impacts of coastal hazards in built settings. If parameters in the mechanics of numerical morphodynamic models derive from non-built settings (Simmons et al., 2017), then their predictions for built settings may be inaccurate. Over decadal time scales and longer, models of “natural” coastal landscape evolution are all but moot in built or intensively managed settings given that “[c]ultural debris and sand washed onto roads is removed almost immediately; inlets created by storms are closed artificially; sand lost from dunes is replaced, first by beach scraping, then by installation of sand fences and vegetation plantings; sand lost from the upper beach is replaced by beach grading; and nourishment projects are implemented to restore the width and volume of the beach” (Nordstrom, 1994a: 506). These interventions, typically bundled in various combinations, are vital to the emergent dynamics of human-altered coasts, but they need better representation in numerical models that reflect the current state-of-the-art (Lazarus and Goldstein, 2019). “Incorporation of both developed and undeveloped locations as test sites can be viewed as a better test of the universality of geomorphological or sedimentological principles than the use of undeveloped sites alone,” Nordstrom wrote (1994a: 508). His vision of humans as endogenous agents of coastal change is closer to realization than it was 30 years ago, but remains a grand challenge for the discipline.

IV Behind the article, looking ahead

A couple of years ago, Karl Nordstrom and I struck up a correspondence. When I told him that I intended to draft this retrospective and asked if I could interview him, he demurred: in January 2020, he retired, professor emeritus, from a long career at Rutgers University and was steering clear of anything that sounded like a professional obligation. But, over time, he replied with thoughtful remarks to questions I had about the origins of the original article.

He figured he was able to write the piece for Progress in Physical Geography in part because he was a geographer and not a geologist. He felt unencumbered by the philosophical adage that “the past is the key to the present,” which tended to ensure that researchers always examined physical coastal
systems as they had been but not as they were—anthropogenic warts and all. Independently, in motivating neogeomorphology, Haff (2003: 20) made a similar observation: “One way to make predictions is to observe the past and then extrapolate into the future….A characteristic of anthropic change, however, is that it has no (deep) geological record. Anthropogenic modification of landscape is a new and unique phenomenon…. [It] is in our interest to engage the study of these changes in a head-on way.” “Head-on” seems an apt description for Nordstrom’s pursuit, especially when many of his colleagues saw pivoting to human-dominated coasts as a risky career move. “Maybe the real reason why I devoted so much effort to studying developed coasts the way I have,” he told me, “is simply because so few other people were doing it.”

That effort turned definitive when he reviewed a proposal for the edited monograph Coastal Evolution (Carter and Woodroffe, 1994), noting that it lacked a chapter on human-altered coasts. In response, Carter invited Nordstrom to contribute one (Nordstrom, 1994b). An Easter egg in Nordstrom (1994a: 508) is the remark, “Articles on the geomorphology of developed systems are usually placed in the back of edited volumes.” That line made me laugh aloud when I saw it again—not only because it winks at “Developed Coasts” (Nordstrom, 1994b) being the last of the 13 chapters in Carter and Woodroffe (1994), but also because I too am familiar with that template (McNamara and Lazarus, 2018). Nordstrom’s book chapter and article for Progress in Physical Geography evolved more or less simultaneously. Where the former focuses on illustrative examples from New Jersey, the latter is more general, and makes a deliberate investment in theoretical scaffolding. The article became the proposal for a book in which human-altered coasts would not be an afterword: the first edition of Beaches and Dunes of Developed Coasts arrived in 2000, the second edition in 2004 (Nordstrom, 2004).

Nordstrom now sees research into human-altered coasts as having entered a difficult phase—the gritty but necessary work of empirical investigation. When his article appeared in 1994, there were no online open-data portals offering high-resolution imagery of the entire planet. Airborne lidar existed, but had yet to revolutionize coastal science with detailed, spatially extended topographic renderings of low-relief landscapes. And post-storm aerial imagery? A catalog of post-storm images since 2003, maintained by the US National Oceanographic and Atmospheric Administration (NOAA), now contains more than one hundred 30 thousand images, and counting—more imagery than a human researcher can reasonably scrutinize without machine help (see Goldstein et al., 2020). Compared to when, not very long ago, Nordstrom was curating descriptions of geomorphic divergences between built and non-built coastlines, these are gloriously data-rich times. There is a ripple of concern among researchers in physical geography that the modern pace of data availability has outstripped theoretical innovation (Koppes and King, 2020). But revisiting literature that predates a data revolution (see Goldstein, 2017), in order to test theories that new data can address, is a classical mechanism of scientific advancement. Testing theory with new evidence—beautiful, messy, confounding—leads to new theory. As Jackson and Nordstrom (2020: 9) conclude in a recent review of research trends in sandy coastal environments over the past 50 years, “Not all unexplored environments are remote.”

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