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Coastal Resilience: Benefits of Wrack and Dune Systems and Current Management Practices

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PURPOSE: The purpose of this US Army Engineer Research and Development Center (ERDC) technical note (TN) is to review both the ecological and geomorphological impacts of wrack on dune systems and provide an overview of current beach dune and wrack management practices. As part of the US Army Corps Regional Sediment Management (RSM) Program, this TN also introduces a case study investigating wrack management solutions for dune stabilization.

BACKGROUND: Vegetative detritus is often intermittently deposited along sandy beaches (Figure 1). This deposited organic material, commonly composed of marine vegetation in the form of seagrasses and macroalgae, is referred to as *wrack* (Dugan and Hubbard 2010; Hemminga and Nieuwenhuize 1990; Sigren et al 2014). Macrophytes that grow secured to the seafloor (e.g., seagrass, kelp, and marsh vegetation) can become detached and free-floating through natural die-offs or high-energy wave events. This material, as well as already free-floating planktonic macrophytes and macroalgae (e.g., *Sargassum*), can become deposited along beaches during particular current, wave, and weather conditions (Reimer et al. 2018). The amount of wrack deposited along a coastline can vary widely depending on location and day-to-day wave and vegetation conditions (Dugan et al. 2011; Reimer et al. 2018). Wrack material serves many purposes in the coastal system concerning foredunes. Its deposition is an essential pathway for nutrient transfer from the marine and adjacent coastal environments to the beach and dunes (Orr et al. 2005; Williams and Feagin 2010; Breithaupt et al. 2019). To that end, wrack material can trap sand and assist with initiating natural dune-building processes (Hemminga and Nieuwenhuize 1990).

Figure 1. Vegetative detritus referred to as “wrack” in Harrison County, Mississippi, beach following Hurricanes Marco and Laura (landfalling 24 and 27 August 2020, respectively).

Despite its importance in the coastal system, wrack is typically treated as a nuisance along managed coasts, particularly along beaches popular for recreation. Many communities choose to rake the beaches, collecting the wrack material along with trash, for disposal offsite (Williams and Feagin, 2010; Sigren et al. 2014). Many studies have speculated that wrack could be utilized in regular management strategies to improve dune systems, both ecologically and structurally (Sigren et al. 2014; Williams and Feagin 2010). Some studies note anecdotally that specific coastal communities will redeposit the wrack and sand mixture removed from the shoreface and berm during grooming along the base of the dunes. However, the impact of this practice has not been studied in the field (Williams and Feagin 2010).

The focus of this TN is wrack deposition along sandy beach coastlines, with specific emphasis on wrack's direct and indirect impacts on coastal ecology and the dune system. Dunes play a crucial role in defending our sandy coastlines, protecting us from the damaging effects of winds, surges, and waves, especially during extreme storm events. With continued severe hurricane activity, sea-level rise, and sediment deficits along the coast, our coastal dunes become more vulnerable, putting our coastal infrastructure at higher risks. Based on data from 2016, 40% of the US population lives along the coast (NOAA Office of Coastal Management 2020). With the population of coastal communities increasing, we must use every resource to prevent the critical degradation of these protective dune systems, including wrack material.

ECOLOGICAL IMPACTS OF WRACK: From an ecological standpoint, wrack has demonstrated significant benefit to biotic communities in the littoral zone and has been strongly correlated with species abundance and heterogeneity. Wrack, composed of naturally deposited vegetation and other detritus, is a significant and valuable source of organic matter in the nearshore (Duggins et al. 1989; Orr et al. 2005). Bacterial breakdown of vegetative detritus provides nutrients to the nearshore water column, contributing significantly to the coastal marine food chain (Harrison and Mann 1975). Wrack is also found to provide critical food for suspension feeders and grazers, such as barnacle and sea urchin species, and nearshore plankton (Duggins et al. 1989).

Vital in the intertidal zones of the beach, wrack material also contributes to coastal ecosystems once washed up along the beach. Wrack on the beach face and berm can be easily accessed and utilized by shorebirds and beach macrofauna, including amphipods, isopods, and insects. Species richness and abundance in these groups significantly correlates with the amount of wrack material washed up on beaches, with the wrack likely providing food and refuge for primary consumers and thus providing prey for predator species (Dugan et al. 2003). Field investigations conclude wrack is critical to maintaining terrestrial-marine connectivity and found talitrid amphipod and insect abundances decreased in response to decreased wrack availability, altering subsidies available to secondary consumers in nearshore and terrestrial ecosystems (Heerhartz et al. 2016). Additionally, studies have suggested a positive correlation between shorebird abundance and wrack cover, due to the availability of macrofauna as a food source (Dugan 1999). Investigations into plover brood foraging habits concluded that, though not a favored habitat, wrack was preferred in locations where more suitable habitats were not present and suggested plovers may depend on wrack when ephemeral pools and bay tidal habitats are not available (Elias et al. 2000). Beyond serving as a critical component of the coastal food chain, wrack material helps coastal organisms indirectly. Wrack benefits from a thermal standpoint show that beaches consisting of wrack of various ages can create microclimates, which allow shorebirds to optimize thermoregulation (Davis and Keppel 2021).

In addition to benefitting the animal kingdom, laboratory experiments show that the addition of wrack supports dune vegetation growth through increased nutrient delivery (Williams and Feagin 2010; Dugan et al. 2011) and increases arbuscular mycorrhizal fungal growth around dune vegetation roots (Sigren et al. 2014). This arbuscular mycorrhizal fungi is essential not only for vegetation health but also for the structure of foredune systems (Koske and Polson 1984).

GEOMORPHOLOGICAL IMPACTS OF WRACK: In natural dune systems, beach wrack is an essential source of organic material and contributes to sand trapping and dune formation (Dugan and Hubbard 2010; Hemminga and Nieuwenhuize 1990). Field observations in sediment behavior along seagrass wrack belts demonstrated accretion in sand (Hemminga and Nieuwenhuize 1990). Accumulated beach wrack, hypothesized to serve as a sediment trap for windblown sand, can initiate dune development via embryo dunes (Hesp 2002) and cyclically establish dune growth as seagrass is continually deposited (Hemminga and Nieuwenhuize 1990). Additional short-term field studies further show improved sediment accretion via aeolian transport over wrack lines compared with other cross-shore zones (Nordstrom et al. 2011). Work performed by the University of Florida, Institute of Food and Agricultural Sciences, investigated using surrogate wrack to enhance dune planting growth and demonstrated that the surrogate wrack improved plant growth and increased sediment accumulation on the dune (Hooton et al. 2019). Whereas wrack lower on the beach serves as a temporary sand trap and embryonic dunes would likely be removed during a storm, beach wrack accumulated on the upper beach can serve as the basis for the seaward growth of foredunes (Nordstrom et al. 2011, 2012).

In natural dune systems, vegetation is well established, and biomass is incorporated extensively throughout the dune form due to multiple burial life cycles of the vegetation. This natural building process results in greater compaction with dunes having higher levels of organic matter and grain-to-grain cohesion (Feagin et al. 2015), increasing the sediment stability and providing more resistance to erosion. However, after a severe storm impact, there is often not enough time to wait for dunes on actively managed beaches to rebuild naturally, which can take a decade or more. Thus, dunes are constructed frequently as part of beach-nourishment projects as a flood risk management or ecosystem enhancement feature. They are typically built to the desired elevation and then planted with appropriate dune-building grasses, such as sea oats, bitter panicum, and American beachgrass (Knutson 1977). Artificial dunes are composed of dredged or mined clean sand and are not representative of mature, natural dune systems. Artificial dunes may also be constructed with a “core,” which may comprise various materials depending on the local environments (Figlus et al. 2015).

BEACH WRACK MANAGEMENT One common beach management practice worldwide is removing washed-up wrack from sandy beaches, a practice called beach raking or grooming (Figure 2). Beach raking, undertaken to ensure clean and attractive beaches, occurs where tourism and recreation contribute significantly to the local economy. Thus, the costs of removing the debris, such as collection, transportation, disposal, and contract management, are justified. Measuring the total economic impact of marine debris is complex and challenging; however, a growing body of knowledge illustrates that even a slight deterioration in beach quality could incur significant financial losses (Balance et al. 2000; Newman et al. 2015).

Figure 2. Harrison County Mississippi, 2020: Groomed beach and equipment used (*top*). Wrack debris line to be groomed including trash that is often washed ashore with the vegetation (bottom).

Mechanical beach raking is a controversial beach management practice as it uses heavy equipment to remove trash as well as natural wrack material that washes onto the beaches from the ocean. Disposal of wrack as waste is common across groomed beaches in the United States (Sigren et al. 2014). The onshore deposition of beach wrack can be significant. For example, an estimated 1200–2179 kg/m[1] per year of kelp is stranded on beaches on the west coast of South Africa (Stenton-Dozey and Griffiths 1983); summer wrack deposition in Barkley Sound, British Columbia, is estimated as high as 140 t/km shoreline (Orr et al. 2005); and a band of wrack approximately 14 m wide and 0.3 m deep was reported lining the Texas coast for over 300 miles in 1950 (Gunter 1979). Given the accumulation of wrack and the offensive smell produced as it decays, it is not surprising that many perceive beach wrack as a nuisance, aesthetically and for public health (Schlacher et al. 2016).

ECOLOGICAL MANAGEMENT IMPACTS: In areas with significant wrack inputs, the coastal ecosystem has developed in part around this regular supply of organic matter. The removal of this material during beach grooming significantly impacts the natural ecosystem structure of these coastal areas (Dugan et al. 2003). Though wrack plays an important role in beach ecology, when it is deposited it may have a variety of undesirable characteristics from a recreational standpoint,

[1] For a full list of the spelled-out forms of the units of measure used in this document, please refer to US Government Publishing Office Style Manual, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–252, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

such as appearance, smell, and attractiveness, to scavenger birds and other species. Occasionally, extreme wrack deposition following a particular weather event, current, or season can be hazardous, unsanitary, and even prevent beach goers from comfortably reaching the water, limiting recreational uses of the beach (Figure 3).

Figure 3. Wrack deposition primarily composed of marsh grasses after Tropical Storm Cristobal (Hancock and Harrison County, Mississippi, June 2020).

Critics of mechanical beach raking argue that wrack removal can have multiple adverse effects on beach ecology. Groomed beaches show reduced abundance and diversity of intertidal macrofauna compared to nongroomed beaches (Deidun et al. 2009; Gilburn 2012; Gonçalves and Marques 2011) and, consequently, the diminished abundance and density of predators, such as shorebirds (Dugan et al. 2003; Engelhard and Withers 1997). An overview of empirical beach-cleaning studies conducted by Zielinski et al. (2019) questions whether the loss of species abundance can be attributed to grooming alone, or impacts related to the intensity of beach use, trampling, and urbanization as groomed beaches are those that are used most intensively, given these impacts are not explicitly separated in several studies. Field experiments investigating wrack removal noted a short-term reduction in *Talitrus saltator*, a species of sandhopper, with the removal of wrack. They hypothesized that continuous grooming might cause significant long-term effects to beach food webs as critical species are reduced (Ruiz-Delgado et al. 2016).

GEOMORPHOLOGICAL MANAGEMENT IMPACTS: Several studies suggest mechanical beach raking disturbs sediment dynamics and morphology of sandy beaches. By removing the wrack, the seaward growth of the dune is restricted (Nordstrom et al. 2012). In addition, Houser et al. (2013) reported a significant decrease in the elevation of the dune crest and base due to the compaction and pulverization of wrack by vehicles driving on the beach. Furthermore, mechanical beach raking uproots, tramples, and pulverizes mature, native plant populations and limits seed, seedlings, and root fragment dispersal, preventing expansion of vegetation coverage and resulting in an increased rate of aeolian sand transport (Nordstrom et al. 2012; Kelly 2014; Dugan and Hubbard 2010). These empirical studies observe that regularly groomed beaches are devoid of topographic variability and characterized by swaths of wide, unvegetated sand.

SUSTAINABLE WRACK MANAGEMENT PRACTICES: Management recommendations to mitigate negative impacts of wrack generally focus on reducing the frequency of mechanical beach grooming. These recommendations include the following: grooming popular beaches only during the tourism seasons, encouraging naturally functioning habitats on low and moderately used beaches by minimizing or eliminating beach grooming, scheduling beach raking around migratory bird season, manually grooming beaches, removing wrack only in cases of substantial accumulation "as needed," and improving public perception of dynamic beaches and acceptance of wrack (Mossbauer et al. 2012; Massachusetts Office of Coastal Zone Management 2013; Zielinski et al. 2019; Robbe et al. 2021). Kelly (2016) advocates compromise management, a solution where beach raking and other human activities are limited to only the lower beach, protecting and supporting natural upper beach habitat without substantial impacts to recreational use.

There are three overarching strategies for managing collected wrack. The first is the recycling, composting, or conversion (e.g., fertilizer, filling for erosion control pillows and mattress, and biochar [Macreadie et al. 2017]) of wrack. Second is offsite disposal, and third is relocation for beneficial use. Whereas disposal essentially removes the wrack from the beach, the relocation of the wrack increases the likelihood that sufficient material remains to protect the ecological and landscape functions described above. One option is to relocate the wrack to nearby stretches of less intensively used beaches. The nutrients released as it decomposes can be redistributed along the beach due to waves, tides, and currents. However, this nutrient contribution is disputed (Engelhard and Withers 1997). The wrack may also be placed locally near native plants to aid in the germination and growth of dune plants through enhanced nutrients and soil moisture or near the dune base as wrack mitigates daily beach erosion by attenuating surge and waves (Deidun et al. 2009; Williams and Feagin 2010; Sigren et al. 2014; Innocenti et al. 2018; Bryant et al. 2019). Solutions considering beach ecosystems and tourism are difficult to achieve, so mechanical beach raking is still common. More research into the economic, biological, and morphological impacts of beach wrack on coastal beaches, as well as its removal, are needed to assist coastal managers in designing policies and practices that balance recreational use and conservation of natural beach environments.

BEACH WRACK MANAGEMENT PRACTICE CASE STUDY—HARRISON COUNTY, MISSISSIPPI: Bryant et al. (2017) outlines in further detail the effect of dune vegetation on coastal foredunes and emphasizes the potential of including vegetation to not only promote growth by aeolian transport but reduce erosion. Recent research at ERDC showed the addition of belowground biomass to the sand during the construction process produced dunes that were significantly more robust in the face of wave erosion, particularly when coupled with aboveground biomass (Bryant et al. 2019). To that end, future projects considering new dune construction may benefit from including organic material mixed in with the sand and existing constructed dune systems may benefit from the incremental addition of organic material to better mimic the natural dune building process.

Sourcing large amounts of organic material for inclusion in new dune construction or for addition to existing dunes may be expensive and logistically challenging. By incrementally introducing into the dune system wrack that naturally is deposited on beaches, the additional biomass material may help to improve dune growth and stability while reducing the need to source large volumes of material for immediate dune construction. This local disposal method also introduces potential cost savings by limiting the amount of material requiring transport off-site.

A case study was designed as part of the US Army Corps of Engineers RSM Program to investigate the potential of incremental introduction of wrack material into dune systems to improve dune stability. This case study utilizes an 1800 ft section of beach located in Harrison County, Mississippi, which contained 11 artificial dunes at the initiation of this work. Working with the Harrison County, Mississippi, Sand Beach Authority, the 1800 ft section was divided into three zones.

Zone 1 was established as the "status quo" zone. In this zone, standard beach wrack management practices, which include grooming of the beach face as well as around and between dunes and ultimate off-site disposal, proceeded as usual and this was strictly used as a monitoring zone. Zone 2 was established as the "no-rake" zone of the test area. In this zone, the grooming and disposal of wrack on the lower beach continued; however, between and around the dunes were to be left ungroomed. Finally, Zone 3 was established as the "no-rake and treatment zone." There was no raking around the dunes in this zone, and the wrack material raked on the beach was placed at the toe of the dunes.

Periodic monitoring, including terrestrial lidar surveys, will occur throughout this case study (Figure 4). The goal of this monitoring, following evaluation of survey data, is to investigate the capability of incremental wrack placement to improve dune stability and recovery. This study also aims to understand further the role of wrack material in the natural growth cycle of dunes. It is expected that the results from this monitoring will demonstrate an improvement in dune accretion in the areas where grooming did not occur, and wrack placements occurred and potentially show improved resilience post-tropical event.

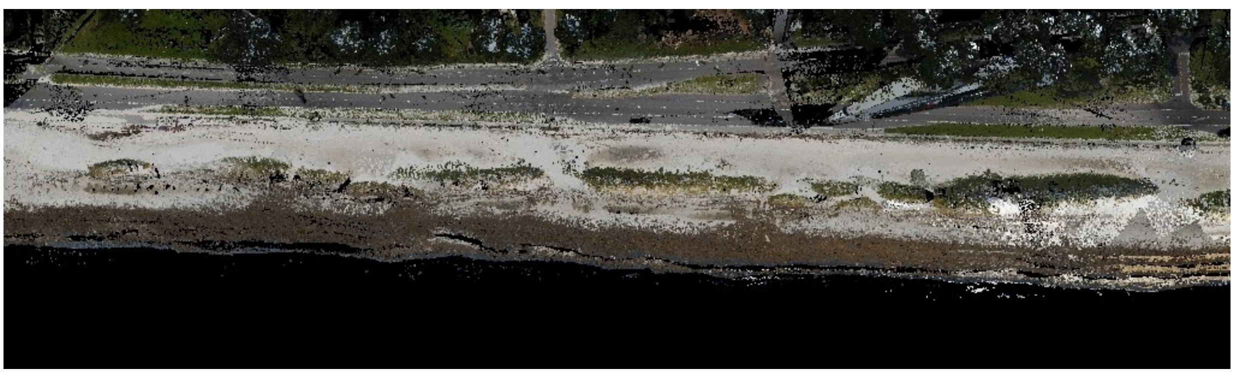

Figure 4. Colorized lidar scan of case-study area.

CONCLUSION: This technical note presents a literature review of the ecological and geomorphological impacts of wrack on dune systems and provides an overview of current beach dune and wrack management practices. Previous field research has shown the presence of wrack material to increase biodiversity, trap sediment, enhance nutrient input, and reduce erosion. Additionally, laboratory investigations have demonstrated the improved resiliency of a dune system following the introduction of biomass. More research is necessary to establish the role strategic wrack placements may play in encouraging the natural growth of dunes and improving stability and resiliency following extreme events. To address this knowledge gap, a field study along the Mississippi Coast to evaluate geomorphological changes due to innovative wrack placements is ongoing as part of the US Army Corps RSM Program.

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