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Biological assessment of dune restoration in south Texas

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ABSTRACT

A dune restoration program was initiated by the City of South Padre Island, Texas in 2010 consisting primarily of plantings of Sea Oats, *Uniola paniculata*, and Bitter Panicum, *Panicum amarum*, and has continued annually thereafter. These restoration efforts were evaluated by comparing selected metrics of ecosystem structure and function among reference and restoration plots ranging in age (time after planting) from 2 to 5 years. Plant and animal communities were examined using a combination of quadrat sampling, funnel traps, pit-falls, and sweep nets. Soil organic content and soil electrical conductivity were also measured. Dune volumes and heights were calculated using a 2013 Lidar DEM. Plant communities were similar across 2 and 4 year-old plots but differed markedly among 2 and 5 year-old plots and between all restoration plots and undisturbed reference plots. After 5 years, restoration plots had 15 plant species, while reference plots had 19. Animal communities followed a similar trend in which all restoration plots differed from the reference plots with the exception of 5 year-old plots which were similar. More time seems necessary for restored dunes to accumulate soil organic matter at levels similar to natural dunes which is still about three times higher. There was a significant positive correlation between plot age and dune heights. These results suggest the native dune plant revegetation as implemented by the City of South Padre Island from 2010 to 2015 is successful in fostering plant and animal community succession and potentially increasing coastal resiliency.

1. Introduction

Sandy beaches and coastal dunes are among the most damaged coastal ecosystems by human activity, which leads to reduced biodiversity, loss of habitat, destruction of protective vegetation, and increased erosion during storms (Nordstrom, 2000; Martinez et al. 2006; Lithgow et al., 2013). Many coastal dune ecosystems occupy the narrow but highly dynamic zone at the interphase of ocean and shoreline urban development, maintaining a protective buffer against storm surge, waves, wind erosion, and providing a critical habitat for adapted flora and fauna. Healthy vegetated dunes provide essential ecosystem services to nearby urban areas (Salmon et al., 1982; Nordstrom, 2000; Schlacher et al., 2011; Mendoza-Gonzalez et al., 2012). Beaches and dunes procure learning, inspirational, recreation, government, commercial, and residential services (Landers and Nahlik, 2013). Coastal dune habitats are more complex than adjacent beaches, generating a diversity of microclimates and habitat for animals and other life forms (Woodhouse et al. 1977; Nordstrom, 2000, Schlacher et al., 2011), enhancing biodiversity. In addition to being structurally important for protecting shorelines, these habitats are ecologically relevant for endangered species (Lithgow et al., 2013) such as the Brown Pelican (*Pelecanus occidentalis*) and Peregrine Falcon (*Falco peregrinus*).

Vegetated dune systems have high aesthetic value, adding amenity and associated economic value to beaches (Salmon et al., 1982; Frampton, 2010; Overton, 2014). Plants play a pivotal role in dune dynamics by strengthening the sediment with root systems reducing erosion, dissipating storm wave energy, and trapping additional wind-blown sediment, which in turn maintains dune growth (Savage, 1963; Woodhouse and Hanes, 1967; Sigren et al., 2014). Vegetation in a typical pioneer zone (i.e. primary dunes) on a sandy beach is limited to a few vigorous, salt tolerant species (Woodhouse and Hanes, 1967; Woodhouse, 1982). Furthermore, structure of plant communities in the backshore is influenced by the microenvironment and is not the result of competition among a limited set of pioneer species (Woodhouse and Hanes, 1967; Adriani and Terwindt, 1974; Lonard and Judd, 2011). For example, *Panicum amarum* and *Uniola paniculata* are two of the most salt tolerant species found on harsh beach environments in South Texas (Dahl et al., 1975; Lonard and Judd, 2011). *U. paniculata* spread vegetatively by rhizomes that help bind sediments, retain soil moisture and nutrients, and increase soil organic material (Woodhouse and Hanes, 1967; Dahl and Woodard, 1977; Long et al., 2013). It is commonly used for revegetation also because of its ability to ameliorate

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harsh abiotic conditions and facilitate the colonization of other plant species (Dahl and Woodard, 1977; Broome et al., 1982). Dunes are usually oligotrophic systems and the structure and composition of typical dune plant communities are determined in part by low levels of available nitrogen (N), phosphorus (P), and potassium (K) (Lithgow et al., 2013). Eutrophication of soils lead to community changes, thus maintaining low nutrient availability may be necessary to the recovery of dune native biota and to avoid invasions (del Moral et al., 2007; Lithgow et al., 2013).

Coastal dune environments are stressful and dynamic, where dune building and habitat succession is commonly a synchronized process (Savage, 1963; Ranwell and Boar, 1986; Nordstrom, 2008). Other than anthropogenic stresses, some natural stresses that modify vegetation community patterns and zonation are salt spray, substrate movement, high temperature, low nutrient and water availability. These stresses create unique habitat diversity along an environmental gradient, typically driven by the distance from the surf zone (Bertness and Callaway, 1994; Monge and Gornish, 2015). Other common abiotic stresses are high temperatures, constant wind, and wave actions (Ranwell and Boar, 1986; Fagherazzi et al., 2003; Monge and Gornish, 2015).

Understanding the ecological processes (e.g. succession) that drive dune community structure and function under various coastal stresses is becoming more important with the increase of storm frequency and intensity associated with climate change (Lithgow et al., 2013). Many urban coastal communities are engaging in efforts to restore dunes in order to recover their associated ecosystem services (Lithgow et al., 2014; Nordstrom and Jackson, 2013; Sigren et al., 2014). In general, coastal dune restoration has not been addressed as frequently as needed, and there is a relatively reduced number of peer-reviewed publications (Lithgow et al. 2013, 2014). Guidelines for dune restoration have been developed since the initial dune restoration experiments in the 1960s and 1970s (e.g. Woodhouse and Hanes, 1967; Adriani and Terwindt, 1974; Davis, 1975; Dahl and Woodard, 1977; Schwendiman, 1977; Salmon et al., 1982; Ranwell and Boar, 1986) (Nordstrom, 2008). With a range of approaches available for restoration and an increasing number of coastlines requiring restoration it is important for managers to be aware of associated costs, effort, and time related to restoration strategies (Martinez et al. 2012; Lithgow et al., 2014). It is necessary to evaluate the effectiveness of these strategies, not only in terms of dune physical stability, but also biologically and in terms of natural habitat. Ecosystem attributes that can be measured to assess natural habitat restoration include biotic community structure, ecosystem function or processes, and resilience to disturbance (Gann and Lamb, 2006).

Common variables used to assess community structure are species diversity, richness, and presence or abundance of exotic species. Lithgow et al. (2013) suggests that ecosystem integrity assessments need to include the monitoring of plant and animal communities. The soil organic content (SOC) is a reliable indicator for monitoring soil degradation and restoration, especially when caused by accelerated erosion (Lal, 2015), as it represents the outcome of plant productivity and litter decomposition, and plays a critical role in sandy soils increasing water retention and cation exchange capacities (Fierro et al., 1999).

Community dynamics and spatial occupation of native plants in well preserved natural dunes have been previously documented in south Texas (Judd et al. 1977, 2008; Lonard et al., 1999). *Sesuvium portulacastrum* a C_3 plant and pioneer species on tropical and subtropical beaches, frequently grows in the backshore topographic zone with *U. paniculata* as the initial species just above the high tide line (Davis, 1975; Lonard and Judd, 1977). Foredunes support *S. portulacastrum*, *U. paniculata,* and occasionally *Panicum amarum*, *Ipomoea stolonifera,* and *I. pescaprae*. *I. stolonifera* and *U. paniculata* are also dominant species found on primary dunes, which are leeward of the foredunes (Judd et al., 1977). *P. amarum*, a long-lived C_4 rhizomatous perennial grass and a pioneer species on temperate and subtropical shorelines, has a significant role in building primary dune systems and stabilizing sand accreting coppice mounds. It frequently occurs on transitory dunes within the backshore zone above the high tide mark (Davis, 1975; Lonard and Judd, 2011).

Table 1
City of South Padre Island use of dredge material for beach nourishment from 1997 to 2015.

Year	Cubic Yards	Total Project	Cost to City
Feb-97	489,211	$1,938,700	$661,259
Feb-99	494,766	$3,136,170	$55,388
Dec-00	366,885	$2,277,893	$177,314
Dec-02	306,402	$2,946,400	$183,210
Jan-05	228,960	$1,495,000	$84,525
Jan-09	406,000	$5,600,000	$139,938
Mar-10	130,000	$1,839,222	$138,750
Mar-11	367,000	$4,017,000	$600,000
Dec-12	210,000	$3,575,646	$372,911
Dec-15	600,000	$6,100,000	$700,000
Totals	**3,599,224**	**$ 32,926,031**	**$ 3,113,295**

Dune restoration activities on South Padre Island (SPI), Texas provide a recent and important ongoing case study of beach management practices that can generate useful information for other developed coastal communities. Particularly as a low-lying barrier island, SPI has a multiple geographical and environmental similitudes to many other Atlantic and Gulf barrier islands (Adriani and Terwindt, 1974). The City of SPI's (hereafter referred to as the City) beach management strategies include sediment nourishments, dune revegetation efforts (up to 100,000 plants/year), and enforcement of beach regulations (e.g., dune protection from anthropogenic impacts).

The City of SPI manages about seven kilometers of beach. In order to enhance shoreline protection, the City organizes nourishments every few years (Table 1) and frequent dune revegetation events with volunteers. Restoration efforts were initiated after hurricane Dolly (2008) when the surge crashed over the bulkheads of the town.

The City's beach was mostly bare of vegetation following hurricane Allen (1980) and subsequent beachfront development. In 2010, the City initiated dune planting events. These plantings have occurred approximately monthly for nine months per year, with 8000–20,000 seedlings per event (approximately 100,000 plants per year produced locally or externally from Texas collected seeds). Revegetation for dune restoration in SPI is a management strategy relying on planting events (Fig. 1), but no subsequent monitoring and assessment was implemented.

With the current revegetation efforts on SPI, it is anticipated that planting native adapted foundation species will provide habitat for more diverse dune plant and animal communities by ameliorating the environmental conditions and allowing additional niches to be colonized, as well as build dunes that have similar volumes to natural well-preserved vegetated dunes. Accordingly, the purpose of this study was to evaluate the City of SPI's dune revegetation program by comparing selected metrics of ecosystem structure and function among reference and restoration plots. The ultimate goal of the restorations is to build areas that will perform well ecologically and build dune structure. It is predicted that (1) as revegetated dunes age, they will resemble preserved natural dunes having similar plant and animal communities, (2) similar soil organic content, and (3) will increase in sand volume.

2. Methods

2.1. Study site

Padre Island is a barrier island off the coast of Texas that extends nearly 182 km south from Corpus Christi to Port Isabel, and is separated from the mainland by the Laguna Madre. The southern portion of the island is known as South Padre Island (SPI), extending 55 km from Port Isabel to the man-made Mansfield Pass where it separates from the