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Research article

Above vs. belowground plant biomass along a barrier island: Implications for dune stabilization

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ABSTRACT

Coastal regions are inherently and increasingly vulnerable and geomorphologically unstable, yet are invaluable economic and residential hubs. Dunes are dynamic buffers to erosion and the most natural, economical, and effective defense for coastal communities. Vegetation is integral to dune structure as it facilitates accretion and stabilization. Differences in the vegetation and root density likely translate to variability in coastal erosion prevention, but this notion has been largely unconsidered. We directly compared stabilizing factors, depth and density, of the root systems of two dominant mid-Atlantic dune plant species, native American beach grass (*Ammophila breviligulata)* and invasive Asiatic sand sedge (*Carex kobomugi*). Despite high plant density, *C. kobomugi* is targeted for removal in restoration efforts as its roots are assumed to provide less effective stabilization than *A. breviligulata*. We collected 30 cores and hand dug 14 *A. breviligulata* ramets at Island Beach State Park, New Jersey to examine biomass, root:shoot ratios, and root density. *C. kobomugi* had a more extensive root system with a root:shoot ratio of 11.36:1 compared to 1.62:1 for *A. breviligulata*. Similarly, cores 60 cm deep and 7.6 cm wide were sufficient to attain fully intact *A. breviligulata* roots, which did not extend deeper than 40 cm, but insufficient for *C. kobomugi* roots which extended beyond the sampling system vertically and horizontally. Scaling these findings to m^{-2}, aboveground biomass is relatively equal, but *C. kobomugi* had over 700% more root mass m^{-2} than *A. breviligulata.* These results have strong implications for dune management. The root system of *C. kobomugi* may be better adapted to stabilize dunes and thus protect coastal areas during small and large-scale perturbations than previously supposed. This is a unique situation whereby the creation of monocultures will hyperstabilize dunes and make them more resistant to erosion at the cost of reduced biodiversity within the framework of resiliency.

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1. Introduction

Coastal areas are inherently vulnerable and geomorphologically unstable by nature of their position as the interface of land and sea, but the effects of climate change - large storms and irregular weather patterns – continue to make the system more susceptible to erosion. Coastal areas (<10 m above sea level) only cover 2% of the Earth's land area, but 10% of the world population inhabits these unstable areas (McGranahan et al., 2007) and economic expansion encourages their further development and global economic output. Natural dune systems are the best defense to stabilize these areas and maintain them as safe working, living, and recreational places; vegetation is the most important biotic component of these habitats as it has direct impacts on the stability and resilience of dune structure. Aboveground shoot mass of vegetation facilitates dune growth vertically and horizontally through sand trapping and belowground root mass provides binding dune structural support to resist erosion (Forster and Nicolson, 1981; Freestone and Nordstrom, 2001; Silva et al., 2016). Aboveground shoots also provide invaluable habitat, incubation sites, and refuge areas for vertebrates and invertebrates (Freestone and Nordstrom, 2001) as well as create drag and thereby

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reduce the flow of storm surge during storm events (Tanaka et al., 2009); roots increase the sheer strength of the substrate and thereby prevent erosion by resisting structural failure during storms (Sigren et al., 2014). Vegetation and biogeomorphology are thus highly coupled in beach-dune systems (Zarnetske et al., 2010) such that plant biodiversity and density are integral to protecting upland infrastructure.

Plant species vary interspecifically in biomass allocation strategies regarding relative investment in root versus shoot components (Poorter and Nagel, 2000). Differing investment among coastal species could have real implications for dune stabilization and erosion prevention. However, this notion has primarily been explored in woody species in backdune maritime forest areas (Tanaka et al., 2009; Sigren et al., 2014) as opposed to the primary dune which is the first line of defense during storms. Coastal regions worldwide vary in flora and support lower diversity than inland areas, but are primarily dominated by only one or two grass species, varying by location because of the high abiotic stress associated with niches in primary dunes (Doody, 2012). For example, species in the genera *Ammophila* largely dominate in both Europe and North America (Eldred and Maun, 1982). Despite the importance of stabilizing grasses, the roots of prevalent dune-building species, native and invasive, have thus far not been directly compared.

The coupling of dynamic geomorphology and intermediate levels of energy in the system make coastal habitats highly vulnerable to top-down impacts of invasive species (Fei et al., 2014). Freed from ecological and pathogenic constraints of native habitats, vertebrates and invertebrates can become virulent and thereby create monocultures when introduced to new areas as invasive species (Rejmánek et al., 2005); this is especially problematic if the invasive directly alters the ecosystem dynamics negatively (Crooks, 2002) thereby reducing or altering the ecosystem services provided by that system. Invasive species can therefore be very problematic as there is a theoretical cost associated with the loss of ecosystem services (Holzman, 2012) and removal efforts are often minimally effective and expensive (Pimentel et al., 2005). However, the associated increase in plant density could further buffer a dune system by preventing wind and surge erosion (Tanaka et al., 2009). Thus far, coastal managers have favored removal and attempted containment of invasives as opposed to allowing stands to expand naturally (Ishikawa and Kachi, 1998; Wootton et al., 2003, 2006).

Historically, dunes are built up over time by native dune-building vegetation species such as American beachgrass (*Ammophila breviligulata*), but the introduction of non-indigenous species has made invasives highly prevalent in most dune systems. For example, though Ammophila breviligulata is a native to the mid-Atlantic Unites States, it is an invasive in the Pacific US as is *Ammophila arenaria,* which is the native dominant supporting most European dune systems (Zarnetske et al., 2012). Similarly, asiatic sand sedge (*Carex kobomugi*) is a highly prevalent component of the vegetation composition stabilizing US mid-Atlantic dunes (Wootton et al., 2005; Burkitt and Wootton, 2011; Reo, 2014). *Carex kobomugi* is a low-lying sedge that is native to parts of Asia and Russia, but since its introduction to the US at the New Jersey coast in 1929, *C. kobomugi* has become a predominant element of the dune flora of US mid-Atlantic dune systems from Massachusetts to North Carolina (Small, 1954; Wootton et al., 2005). The introduction of a new species like *C. kobomugi* likely feeds back dune biogeomorphology.

A regime shift in dominant species can result in changes in aboveground (Small, 1954; Wootton et al., 2005; Fei et al., 2014) and belowground (Johnson, 2011; Day et al., 2015) community composition and may translate to geomorphological changes in dune structure and stature (Lea and McLaughlin, 2005; Zarnetske et al., 2012); differences in vegetation density and rooting structure likely lend to the inherent variability in topography that categorizes dunes (Houser and Mathew, 2011), translating to variability in stabilization to resist coastal erosion. Wind tunnel experiments, have shown a species effect in sand capture (Zarnetske et al., 2012), but this has not been tested *en situ* (Sigren et al., 2014). Despite the important role of *A. breviligulata* in stabilizing coastal (Gemma and Koske, 1997; Emery and Rudgers, 2014) and lacustrine systems (Cowles, 1899; Lichter, 2000), the morphology and physiology of it and native and invasive counterparts are poorly studied. *Ammophila breviligulata* is considered well adapted as a dominant native stabilizing species in the United States. The US Department of Agriculture characterizes the native as having an extensive root system with a minimum root depth of 50 cm (2012); however, there is insufficient literature reporting the actual depth of the species in field studies. Comparatively, *C. kobomugi* is shorter in stature, more low-lying to the sand surface, (Min, 2006), known to produce high density monocultures (Wootton et al., 2005; Reo, 2014) of 140 ramets m^{-2} versus 40 ramets m^{-2} (Wootton et al., 2005; Reo, 2014) and produces short-roots to a depth of 60 cm with sympodial long-roots that are believed to go much deeper (Ishikawa and Kachi, 1998). These morphological and density differences may translate to discrepancies in total biomass and thus varying resistance to erosion based on vegetation composition.

We directly compare the biomass allocation and substrate characteristics of coastal areas dominated by *A. breviligulata* and *C. kobomugi*. To do this we took cores *in situ* at Island Beach State Park, New Jersey, an area directly affected by and prone to erosion from future storms like Superstorm Sandy. We believe that compared to *A. breviligulata*: (1) *C. kobomugi* will have a denser and deeper root structure translating to greater belowground biomass; and (2) *C. kobomugi* will have a greater investment in root than shoot mass.

2. Materials & methods

***Field Site*:** We collected our data in the primary dunes of Island Beach State Park (IBSP), New Jersey (Fig. 1). The park is a barrier island containing ≈17 km of sandy beach shoreline located on the Barnegat Peninsula in Berkeley Township, Ocean County, NJ. The coastal habitat represents the longest continuous natural dune system in NJ and transitions from littoral inland to dune, maritime forest, and maritime marshes. Prior to Superstorm Sandy (October 27-November 1, 2012), the park contained a largely continuous dune system. However, Superstorm Sandy caused discontinuous erosion such that the primary dunes of more northerly beach areas (A1-A14) were compromised and experienced high erosion, overwash, wind blowouts, and scarping. The primary dunes in the southernmost part of the park (A15-A24) were eroded, but not destroyed and the vegetation composition is representative of those found across mid-Atlantic coastal dunes, dominated by *A. breviligulata* (AB) or *C. kobomugi* (CK). CK was introduced to the US at IBSP in 1929 as a singular contained patch, thus, stands are historically the oldest in the US (Small, 1954).

***Data Collection*:** We collected cores to measure the depth and density of living root biomass. We extracted cores from distinct and undisturbed primary dune vegetation stands, dominated by CK or AB respectively, that were haphazardly selected walking the dunes in A18-A21; stand selection could not be random, as species are not evenly distributed atop dunes. Ramet selection within stands was random. Prior to extracting cores, we measured the height of the tallest leaf of the ramet being cored. We collected 15 cores (60 cm in depth and 7.6 cm in diameter) of each species using metal piping and a custom pipe jammer. All cores contained the total