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Live and dead shrubs and grasses have different facilitative and interfering effects on associated plants in arid Arabian deserts

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ABSTRACT

The Arab Gulf desert region is dominated by few shrubs and grasses, although mostly devoid of vegetation. The impact of both live and dead shrubs and grasses on plant diversity and community composition on sand dunes of the United Arab Emirates was assessed. Species richness, diversity indices (Simpson, Shannon–Wiener, and Brillouin), and plant abundance were significantly greater under dead grasses than in the surrounding open areas. However, the opposite was true for live grasses. Dead and live shrubs did not differ significantly in species richness and abundance. The relative interaction index indicated that live nurse grasses inhibited 13 species and facilitated only one species, whereas dead grasses facilitated 13 species and did not inhibit any species. Live shrubs facilitated four species and inhibited two, but dead shrubs facilitated 10 species and inhibited none. Organic matter and most of the assessed soil nutrients were significantly higher under both shrubs and grasses than in the barren spaces in-between. The facilitative effect of dead grasses on soil characteristics was more obvious. The results support the feasibility of growing nurse shrubs and grasses to restore degraded arid desert environment.

1. Introduction

Plants can exert influence on their neighbors in myriad ways, resulting in a broad range of harmful or beneficial outcomes. The abundance, performance, and spatial distribution of plant species are markedly related to the strength and sign of their interactions in communities (Roughgarden and Diamond, 1986; Brown et al., 2001). Understory plants can exert both facilitative and competitive effects on larger neighboring "nurse" plants. Their benefits include reduced thermal stress or evapotranspiration (Valiente-Banuet and Ezcurra, 1991; Greenlee and Callaway, 1996); improved soil texture, nutrient content, and water availability (Nobel, 1989; Moro et al., 1997; Barnes and Archer, 1999; Pugnaire et al., 2004); and protection from herbivory (Haase et al., 1997; Brown and Ewel, 1987). Conversely, nurse plants can also have negative effects on the survival and establishment of the associated understory plant community. These plants may interact competitively through light deprivation, competition for water and nutrients, or leaching of allelopathic compounds (Nobel, 1989; Barnes and Archer, 1999; Holmgren et al., 1997; Kitajima and Tilman, 1996; Moro et al., 1997). In general, the net direction and strength of these interactions are considered to depend on the severity of the physical environment (Bertness and Leonard, 1997) and site productivity (Bruno et al., 2003). It has been hypothesized that facilitative interactions may be more prevalent in harsh environments, such as those occurring in arid and semiarid environments (Callaway, 1995; Callaway and Walker, 1997; Gómez-Aparicio et al., 2004).

In terms of depth, grass roots are generally distributed nearer to the surface than shrub roots. In their global analysis of root distribution, Jackson et al. (1996) indicated that 44% of grass roots were found in the top 10 cm of soil, whereas only 21% of shrub roots were found at the same depth. In addition, Schenk and Jackson (2002) collected a data set of >1300 records of root system sizes for individual plants from various water-limited ecosystems, including deserts. They concluded that root system sizes differed among growth forms: annuals < perennial forbs = grasses < semi-shrubs < shrubs < trees. Furthermore, in the arid Patagonian

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steppe, Soriano et al. (1987) indicated that 54% of the grass-root biomass is located in the top 10 cm of the soil. However, most of the shrub roots are found in the lower layers of the soil (Soriano et al., 1987). Consequently, the root system of grasses allow uptake of water mostly from the upper layers of the soil with frequent and short-duration pulses of water availability. However, shrubs take up most of the water from the lower layers of the soil with infrequent and long-duration pulses of water availability (Sala et al., 1989). As shrubs and grasses use soil water and nutrients differently, their interference or facilitative interactions with the associated plants might be affected.

It has been reported that shading by a nurse plant canopy reduces the solar radiation intensity and temperature at the soil surface and, consequently, water losses by evaporation (Moro et al., 1997; Maestre, 2002; El-Bana et al., 2003). However, the canopy effect depends on the density of the crown. Open canopies, such as that of arid grasses and dead shrubs, have less significant effects on shading and water losses by evaporation from soils, compared to live shrubs with denser canopies. Soil fertility is another highly significant factor that would enhance the facilitation effects of both live and dead nurse plants (Belnap, 1995). The soil fertility under recently dead shrubs is expected to be similar to, if not higher than, live shrubs. In addition, live plants can compete with the understory community. Although several studies assessed the facilitative/inhibitory effects of live nurse shrubs and grasses, few studies compared the effects of dead and live nurse plants on associated plants (Morris and Wood, 1989). The impact of dead and live shrubs and grasses on the physical and chemical characteristics of soil and on the understory vegetation can be assessed. This would further enhance our understanding of the plant–plant interactions and the implications for their use in restoring degraded arid desert environments.

Several studies have assessed the impact of trees and shrubby plants on the associated plants in the arid lands of the Arab Gulf region (Brown et al., 2001; El-Bana et al., 2003, 2007; El-Keblawy and Abdelfatah, 2014). However, the similar impact of grasses has not been studied. In addition, several studies have assessed the impact of grasses on associated plants in the Mediterranean semiarid climate (Maestre et al., 2003; Padilla and Pugnaire, 2006; Cortina et al., 2011). However, this was not studied in hyperarid environments with highly limited water and nutrients. With their shallow adventitious root systems, grasses rely mainly on atmospheric moisture and sparse rain showers (Jackson et al., 1996; Soriano et al., 1987; El-Keblawy et al., 2009); therefore, grasses and the associated plants are expected to compete intensively on the very limited available resources in the sandy soils of arid lands. However, shrubs, with their deeper root systems that allow water uptake from a deeper layer, are expected to compete less intensively with the associated plants. We hypothesized that live grasses have more competitive and less facilitative effects on their associated species than shrubs do in resource-limited arid environments.

In most desert ecosystems, vegetation is spatially heterogeneous, consisting of vegetation patches with alternating areas of bare soil (Bertiller, 1998). Typically, desertification of sandy areas due to wind erosion often results in the dominance of few shrubs and grasses, while most of the land is devoid of vegetation (Kéfi et al., 2007; Zhao et al., 2007). As dead and live shrubs and grasses exert different interactive effects on the associated species (Morris and Wood, 1989), understanding their facilitative/interfering effects on the survival of understory shrubs and annuals is very important in sustainably restoring degraded arid and semiarid ecosystems with potential nurse plants (Kéfi et al., 2007; Zhao et al., 2007).

The use of nurse plants has been recommended for restoring degraded ecosystems, where physical conditions or grazing pressure significantly limit plant establishment (Anthelme et al., 2014; Padilla and Pugnaire, 2006). Nurse plants can maintain greater biodiversity (Valiente-Banuet et al., 2006; Valiente-Banuet and Verdú, 2007). As hypothesized, the importance of facilitation increases with increasing severity of the abiotic conditions, therefore also increasing the benefits of nurse plants under stressful conditions, such as arid deserts (Callaway and Walker, 1997; Callaway et al., 2002). The aim of the present study was to assess the impact of live and dead shrubs and grasses on plant diversity and community structure of stable sand dunes in the Dubai Desert Conservation Reserve (DDCR), United Arab Emirates (UAE). The study also aimed to assess the impact of dead and live shrubs and grasses on the physical and chemical properties of soil.

2. Materials and methods

2.1. Study site

The DDCR (24–25° latitude and 55–56° longitude) has been declared for conserving the natural flora, fauna, and landscape of the desert ecosystem in Dubai, UAE (Fig. 1). It is an arid area, characterized by two distinctive seasons: a long dry season (April to November) with very high temperatures, and a short season (December to March) with mild to warm temperatures and light rainfall. The mean daily temperature ranges between 12.1 °C in January and about 42 °C in June–August. The average rainfall recorded in the long term (1934–2004) is 102.8 mm. However, the variations in annual rainfall are considerable. A maximum of 345 mm was recorded in 1957, whereas a minimum of 3.0 mm was recorded in 1985 (Feulner, 2006). The growing season of the study year (October 2009 to May 2010) was much drier than average; the total rainfall was only 24.4 mm at the new Al-Faqa metrological station (about 15 km away from the study area).

The DDCR is a fenced area with a perimeter of about 85 km and an area of 225 km^2. The reserve was declared in 2002, and the perimeter was completed in late 2003. The DDCR is mainly a desert ecosystem with sand dunes. The topography is simple, with a dominance of low to medium–high sand dunes. The plant community of the DDCR is not rich. It is dominated by few shrubby species, such as *Leptadenia pyrotechnica*, *Calligonum comosum*, *Dipterygium glaucum*, *Fagonia indica*, *Heliotropium digynum*, *Limeum arabicum*, *Moltkiopsis ciliata*, and *Indigofera colutea*. Short live ephemerals appear immediately after rainfall, with their life span extending to the end of the season (April/May), depending on the availability of rainfall. *Prosopis cineraria* is the only tree recorded in the reserve. The DDCR has a large population of wild antelopes, such as oryx and gazelles. These antelopes are given externally sourced feed, which meets probably about half of their dietary requirements.

2.2. Assessing the interactive effects on associated plants

Each of the live and dead shrubs and grasses was represented by 30 individuals, except for live grasses being represented by 22 individuals. The selected grasses were undamaged tussocks. Due to overgrazing by the overstock of antelopes in the study area, the number of undamaged grass tussocks was rare during the study year, which received only 24.4 mm of rainfall. Whenever possible, dead plants were selected from among those that died in the last two seasons; the stems were still undamaged and lighter in color, compared with older skeletons.

The live nurse shrubs included *L. arabicum* (seven individuals), *Rhanterium epapposum* (seven individuals), *D. glaucum* (eight individuals), and *Crotalaria aegyptiaca* (eight individuals). The studied nurse grasses were *Pennisetum divisum* (12 individuals) and