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ORIGINAL PAPER

Resistance of red mangrove (*Rhizophora mangle* L.) seedlings to deflection and extraction

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Abstract Red mangrove (*Rhizhophora mangle* L.) is the dominant tree species in the intertidal zone of ecosystems on the Atlantic shores of the Caribbean and tropical western Atlantic. The propagules of this species are initially buoyant, becoming negatively buoyant before rooting in a variety of substrates. After establishment, these seedlings form aerial roots, leading to communities of plants with complex networks of stems and aerial roots. While established mangrove communities assist in stabilizing coastlines, seedlings are susceptible to wave, current and wind energy and this limits the habitats that they can successfully colonize. In this experiment, the mechanical resistance of seedlings growing at five locations with different substrate and canopy conditions was tested. The 78 seedlings tested ranged in height from 27 to 47 cm, had between one and ten pairs of leaves but had not yet formed aerial roots. Seedlings were pulled horizontally. The reaction force at 20° deflection in four cardinal directions and then force to failure in the landward direction was measured. Seventy-five percent of the seedlings failed in the root system. The remainder failed near the base of the stem. Larger seedlings were more likely to fail at the roots. Seedlings growing outside of mangrove overstory on coral rubble were 3.5 times more strongly anchored than those growing within the mangrove overstory on sand. In spite of directional loading by waves and on-shore breezes, the deflection resistance did not vary systematically with pulling direction. Seedling anchorage varies among locations with different overstory and substrate conditions, likely due to differences in competition and acclimation to wind and wave energy along with differences in rooting among substrates.

Keywords Failure resistance · Mangrove · Mode of failure · Natural disturbance · *Rhizophora mangle* · Wave damage · Wind damage

Introduction

Mangroves are a specialized group of woody plants that form intertidal fringing communities along the coastlines of continents, islands and atolls throughout the tropics. Mangroves grow in one of the most mechanically challenging environments of all plants, being subject to a gradient of wind and wave energy from quiet lagoon environments to shorelines with full exposure to tropical storms (Doyle and Girod 1997; Tomlinson 1986). These communities provide a number of critical ecosystem services including shoreline protection from waves, storms and tsunamis, fisheries, carbon fixation and tourism. They are under considerable pressure from development, and the projected consequences of global warming, sea level rise and increased storm severity, will place these ecosystems under further stress (UNEP-WCMC 2006). The biomechanics and disturbance ecology of mangroves are complex. While established mangrove communities appear mechanically robust and dissipate routine wind and wave energy (e.g. Mazda et al. 2006), they are periodically damaged by extreme winds, wind driven waves, and storm surge during severe storms. For example, Hurricane Mitch in 1999 destroyed over 90% of the mangroves on islands in Honduras through defoliation, uprooting, burial, and erosion (Cahoon et al. 2003). Stoddart (1963) reported similar

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