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ORIGINAL ARTICLE

Mangrove rehabilitation on Carey Island, Malaysia: an evaluation of replanting techniques and sediment properties

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ABSTRACT
We assess the suitability of conventional replanting techniques of *Rhizophora mucronata* and the relationship with soil properties, and compare the differences between rehabilitation and non-rehabilitation sites, on Carey Island, Malaysia. The average survival rate of planted seedlings at the rehabilitation site was 46% in the first six months, gradually reducing to complete mortality after one year, while no survival was recorded at the non-rehabilitation site from the beginning. Over the short period, survival of the clumped planting technique yielded the highest survival rate (75%) compared with random (33%) and uniform (30%) techniques; with a height increment of 2.48 ± 1.87 cm/month, diameter increment of 0.49 ± 0.81 mm/month, leaf increment of 2.05 ± 2.80 and chlorophyll content of 32.08 ± 5.80 SPAD (= Soil Plant Analysis Development values). Fifteen new recruits of *Avicennia* spp. with a 60% survival rate were recorded in the rehabilitation site at the end of the study. Soil texture changed significantly at the rehabilitation site from sandy loam (clay, 2.85%; silt 33.93%; sand, 63.21%) to silty loam (clay, 1.88%; silt 60.74%; sand, 37.38%). Soil nutrients: carbon (C), nitrogen (N) and potassium (K) were significantly higher in the top 40 cm at the rehabilitation site while phosphorus (P) was lower. We argue that nutrient differences between the rehabilitation and non-rehabilitation sites affected the health of both planted and wild seedlings and ultimately the success of the rehabilitation effort. As the soil condition improves at the rehabilitation site, natural recruitment would be the best available option in this restoration process.

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Introduction

Mangrove forests are important ecosystems in tropical and subtropical coastal areas with significant ecological and societal contributions. These ecosystems are crucial not only from the perspective of the environment, but also in terms of their economic value (Bosire et al. 2008; Kamali & Hashim 2011). Recent reduction in the quality and quantity of the mangrove forests has been widely documented. Since 2000, it has been estimated that global mangrove forest areas have been reduced by 1% per annum with concomitant reductions in the ecosystem services they provide (Giri et al. 2008). In 2007, the Food and Agricultural Organization (FAO) reported that around 15,000,000 ha of mangrove forests were still in existence worldwide. However, Giri et al. (2011) showed that the forested areas had been reduced to 13,000,000 ha and Malaysia had 505,386 ha (3.7%) of the extant mangrove forests, placing it sixth in terms of worldwide total global forest coverage.

Mangrove ecosystems are dynamic due to their location in the intertidal zone between the land and the water (sea and river), where they are affected by both land and seaward zone activities (Nagelkerken et al. 2008). The destruction of mangrove forests is partly due to climate drivers such as global warming, rising sea level, and storms or cyclones (Thampanya et al. 2006; Salmo III et al. 2014). For example, Jusoff (2013) discussed the constant, annual rate of sea level rise that has depleted some mangrove areas. Mangrove forests can also be destroyed by anthropogenic activities such as land use for urbanization and coastal development, including aquaculture and agriculture activities (Giri et al. 2011; Jusoff 2013).

In order to preserve these valuable ecosystems, rehabilitation efforts have been initiated, particularly in developing countries such as Malaysia, Thailand and the Philippines (Thampanya et al. 2006; Primavera & Esteban 2008; Kamali & Hashim 2011; Salmo III et al. 2013). However, rehabilitation efforts often fail. This

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