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Influence of stand age on sediment bacterial communities in restored mangrove forests

Jiayong Lai [a], Kishneth Palaniveloo [a], Sahadev Sharma [a], Rozainah Mohamad Zakaria [b], Wee Cheah [a,*]

[a] Institute of Ocean and Earth Sciences, Universiti Malaya, Kuala Lumpur, Malaysia
[b] Institute of Biological Sciences, Faculty of Science, Universiti Malaya, Kuala Lumpur, Malaysia

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ABSTRACT

Microbes in mangrove sediments provide essential ecological functions, acting symbiotically with their mangrove hosts. Investigating their dynamics in restored mangroves over a chrono-sequence offers valuable indications on how microbial diversity is shaped by both restored mangrove age and environmental factors. In this study, we examined the dynamics of the bacterial community and sediment properties in four *Rhizophora apiculata* forests restored at different times, as well as the sediments of an intact *Avicennia marina* forest. The result indicated that higher diversity and abundance in older restored mangroves were supported by higher nutrients in sediment, particularly carbon content (ANOVA, $p < 0.01$). The most dominant bacterial phylum Proteobacteria, showed decreasing relative abundance with sediment depth, while Chloroflexota exhibited increasing relative abundance. The bacterial community demonstrated a strong correlation with sediment properties, especially salinity and carbon content. Co-occurrence network analysis revealed increasing module counts in younger restored mangrove forests, with stabilised counts observed at the 9 years suggesting established bacterial functional dynamics by this age. Random attack of network analysis also indicated that the 5- and 9-year-old mangrove forests were more fragile, while the 16 year-old mangrove forests displayed lowest resilience due to higher salinity levels. In contrast, the 21-year-old restored mangrove and intact *A. marina* exhibited robust and well-connected networks. In summary, older *R. apiculata* restored forests fostered enhanced soil nutrient content, especially surface sediment carbon content, and supported a more stable, diverse bacteria community network.

1. Introduction

Mangroves, the vegetation that thrives in intertidal brackish and saline waters, rely on the mutual interactions with diverse microbial assemblages, much like terrestrial plants depend on soil microbes (Zhuang et al., 2020). The sediment from mangrove ecosystems contains more organic carbon due to the mangrove plant litter, root exudates, and sedimentary nutrients from terrestrial and stored in anaerobic conditions (Alongi, 2014; Alongi & Mukhopadhyay, 2015; Zhu et al., 2018). Mangrove vegetation is further enhanced by the microbial communities, which convert complex organics from dead plants into a simpler form of nutrition symbiotically. The direct proof of these functions lies in the mangrove trees' capacity to change soil conditions through peat formation, amassing fine roots, and altering sedimentation patterns among others (Alongi, 2005).

The ecological services provided by mangroves such as mitigating coastal erosion, protecting coastal communities from storm surges, and enhancing biodiversity by providing habitats for both marine and terrestrial species have led to growing recognition of their socio-ecological importance in recent decades (Menéndez et al., 2020; Mukherjee et al., 2014). This increased awareness has driven numerous conservation and restoration initiatives, particularly in Southeast Asia after the 2004 Indian Ocean Tsunami, which highlighted the critical role of mangroves in coastal protection (Barbier, 2006; Koh et al., 2018; Srinivas & Nakagawa, 2008).

A recent study found that up to 75 % of carbon (C) stocks were stored in planted mangroves compared to intact matured stands, with *Rhizophora* spp. surpassing other mixed mangrove genera in carbon storage potential (Bourgeois et al., 2024). Additionally, emerging research highlights the crucial role of mangrove ecosystems in blue carbon

* Corresponding author.
E-mail address: wee.cheah@um.edu.my (W. Cheah).

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