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Early growth adaptability of four mangrove species under the canopy of an introduced mangrove plantation: Implications for restoration

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ABSTRACT

In China, large-scale mangrove afforestation has been performed over the last two decades using introduced species. The large areas occupied by the introduced *Sonneratia apetala* have generated some concerns of biological invasion. The aim of this study was to investigate the feasibility of planting native mangrove species under the canopy of *S. apetala* plantations and the best species to acclimate under low light conditions in the understory. A 360-day experiment was conducted with four dominant mangrove species in southern China (*S. apetala*, and three native species *Kandelia obovata*, *Aegiceras corniculatum*, and *Bruguiera gymnorhiza*) in four habitats (i.e., bare mudflat, two-year plantation, six-year plantation, and eight-year plantation) with different light irradiance conditions. Results showed that in terms of propagule germination and seedling survival, the low light irradiance condition impeded the early growth of *S. apetala*, but had less impact on *B. gymnorhiza*. With decrease in light irradiance, increments in stem height, basal area, and leaf area, and relative growth rate decreased the most for *S. apetala* and the least for *B. gymnorhiza* among the four species. In terms of the physiological response parameters of net photosynthesis rate, stomatal conductance, and transpiration rate, *B. gymnorhiza* exhibited more adaptability than *S. apetala* under dense canopies. With respect to the response of early growth of seedlings over 12 months, *B. gymnorhiza* was the most adaptable species to the understory low light condition, while *S. apetala* was the most adversely affected species. The information from this study should be useful for the introduction of native species into plantations of introduced mangrove species to improve their conservation value.

1. Introduction

Mangroves are unique intertidal wetland ecosystems along tropical and subtropical coastlines. Due to rapid economic development and increasing population, mangroves have suffered from global degradation and retreat over the last few decades (Saenger, 2002). The mangrove area in Asia has decreased from 42% of the global total in the early 1990s to 39% at present. As one of the hotspots for mangrove loss in the world, the mangroves along the South China Sea have declined from 5.79 million ha in 1980 to 4.05 million ha in 20 years (UNEP, 2004).

Nevertheless, the importance of mangrove ecosystems has stimulated activities of mangrove introduction or afforestation. Since the 1970s, some large-scale or successful cases have been reported from Florida (Lewis, 2000), Australia (Saenger, 1996), and the Sundarbans (Saenger and Siddiqi, 1993). Thereafter, the ecological effects of introduced mangroves have been addressed by studies in West Africa (Rubin et al., 1998; Sunderland and Morakinyo, 2002), Hawaii (Sweetman et al., 2010), and French Polynesia (Polidoro et al., 2010). In China, massive mangrove afforestation has occurred extensively since the 1980s (Lin and Fu, 2000). After the 1990s, the main native species (*Kandelia obovata*) in mangrove reforestation programmes has been replaced by the introduced *Sonneratia* species, owing to the faster growth and more adaptive characteristics of the latter (Zan et al., 2003). Since 2000, *Sonneratia apetala* has proliferated as a plantation

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species and naturalized populations have been recorded from 22 counties of Guangdong Province, which has the longest coastline among the provinces in China. Because of the large area of *Sonneratia* plantations, some concerns of biological invasion have been raised. Ng and Corlett (2002) reported that *S. apetala* exhibited invasive characteristics at the Mai Po Ramsar site (Hong Kong) where the bare mudflat and tidal channels were colonized by this exotic species. The dispersed *S. apetala* seedlings were presumed to have originated from the plantations on the opposite side of Shenzhen Bay. The characteristics, such as fast growth and high spreading ability of *S. apetala* that may affect native mangrove community structure, have been investigated in a 10-year monitoring experiment (Ren et al., 2009). However, Zan et al. (2003) suggested that the likelihood for *Sonneratia* to pose a threat in biological invasion was low because the species was not self-regenerating in Shenzhen Bay. In addition, a niche survey conducted at the natural mangrove stands mixed with a 20-year plantation indicated that the native populations occupied the most niches, while the exotic *S. apetala* and *Sonneratia caseolaris* were restricted to a narrow tidal zone (Liao et al., 2005). Irrespective of the invasiveness of *Sonneratia* species, using non-native species for mangrove afforestation is generally ethically unacceptable. How to manage plantations of exotic species so as to minimize their ecological impact is also necessary. One of the possible management approaches is to see if native species can be re-established in *S. apetala* plantations, which depends on their ability to colonize the understory of existing plantations.

Peng et al. (2008) explored the establishment of mixed stands and combination of native species with *Sonneratia* plantations. Light penetration in a salt-stressed environment can be a major limitation to population recruitment in natural mangroves and may also limit the understory of mangrove plantations with a dense canopy (Janzen, 1985; Lugo, 1986). For example, shading significantly affected seedling growth and morphology of *Xylocarpus granatum* and differences in tree height increased with experimental duration (Allen et al., 2003). Similar results were observed in southern Thailand where the growth in height of *Rhizophora apiculata*, *Bruguiera parviflora*, and *Bruguiera cylindrica* under open canopy conditions was over 10 times that of shaded seedlings based on field plot measurements (Tamai and Iampa, 1988). For early growth of *Laguncularia racemosa* in Florida, population densities were greater at the edge and near open water plots than in inner and inland plots (Proffitt and Devlin, 2005). Lack of light penetration has been demonstrated as the main limiting factor in early growth for mangroves. However, low light tolerance species, such as *R. apiculata*, *Bruguiera gymnorhiza*, and *Xylocarpus* spp., colonize usually under closed canopies rather than gaps (Imai et al., 2006). Differences in nutrient uptake efficiency among species may also combine with shade tolerance, as shown by the replacement of *L. racemosa* by *Rhizophora mangle* and *Avcennia germinans* in the mature forests of Acarajó in Brazil (Berger et al., 2006).

At present, Guangdong Province has the largest introduced population of *S. apetala* in China. The natural mangrove formation is dominated by *K. obovata* and *B. gymnorhiza* at the tree layers, and by *Aegiceras corniculatum* at the shrub layers (Li and Lee, 1997). Usually, the lower tidal zone is afforested with *S. apetala* for its rapid growth and surpassing adaptive characteristics over native species; the mid-tidal zone is mainly characterized by *K. obovata* and *A. corniculatum*, and the higher tidal zone is vegetated by *B. gymnorhiza*. Consequently, *S. apetala* is considered as the pioneer species, *K. obovata* and *A. corniculatum* are mid-term species, and *B. gymnorhiza* the late-stage/climax species (Wang and Wang, 2007). Therefore, the objective of this study was to investigate (1) whether it was possible to plant native mangrove species under large *S. apetala* plantations; and (2) which species acclimated best under low light penetration conditions at the understory. The hypothesis was that the species dominating the later stages of mangrove forest development should be more adaptable to low light conditions than those of earlier stages. The results will inform planting decisions to improve exotic species plantations using native species.

2. Materials and methods

2.1. Study site

The study site is located in the Yifeng Estuary of Shantou City (Fig. 1). Tides are semi-diurnal with a tidal range of 2.1 m. Salinity of seawater ranged from 0.2 to 22.1 in 2011. Since 1998, mangrove plantations were established, with *S. apetala* and *K. obovata* comprising about 90% and 5% of the total mangrove area, respectively. Other species, such as *S. caseolaris* and *A. corniculatum*, have also been planted, occupying the other 5% of total area. Three extensive afforestation initiatives using *S. apetala* were conducted in 2010, 2008, and 2004. The community structure and environmental

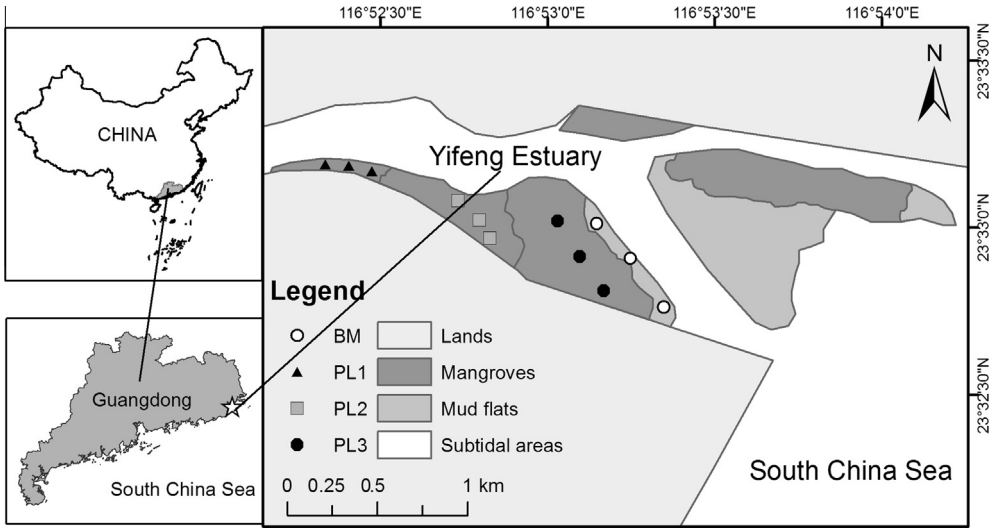

Fig. 1. Sketch map of field trial sites in mangrove plantation at the Yifeng Estuary. The abbreviations of sites refer to bare mudflat (BM), and in two-year plantation (PL1), six-year plantation (PL2), and eight-year plantation (PL3), respectively.