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Does energetic cost for leaf construction in *Sonneratia* change after introduce to another mangrove wetland and differ from native mangrove plants in South China?

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ABSTRACT

Exotic species invasions are serious ecological problems. Leaf construction cost (CC) and growth traits of two *Sonneratia* (*Sonneratia caseolaris* and *S. apetala*) and four native species (*Bruguiera gymnorrhiza*, *Kandelia obovata*, *Aegiceras corniculatum* and *Avicennia marina*) in Hainan and Shenzhen mangrove wetlands were compared to evaluate invasive potentials of *Sonneratia* after introduced to Shenzhen, their new habitat. There were no significant differences in CC and growth traits between two wetlands, suggesting *Sonneratia* did not lose any advantage in the new habitat and were competitive in both wetlands. CC per unit mass (CCM), CC per unit area (CCA) and caloric values of *Sonneratia* were significantly lower than those of native mangrove species while specific leaf area (SLA) was just the opposite. CCM of *S. caseolaris* and *S. apetala* were 6.1% and 11.9% lower than those of natives, respectively. These findings indicated the invasive potential of *Sonneratia* in Shenzhen after their introduction.

1. Introduction

Biotic invaders, brought about largely through human activities, are species that establish a new range in which they proliferate, spread, persist and damage natural environment (Mack et al., 2000). These invaders alter fundamental ecological properties and physical features of an ecosystem, leading to significant global economic losses (Barney et al., 2013; Simberloff et al., 2013; Marbuah et al., 2014; Doherty et al., 2015). Because of the damages caused by biotic invaders, many attempts have been made to construct lists of common traits shared by successful invaders (Parker et al., 2013; Simberloff et al., 2013). The exotic species having ruderal, early-successional life-history characteristics, such as high photosynthetic efficiency, rapid growth, early and high reproduction, short life spans and resistance to herbivore attack, are generally considered to have invasive potentials (Reichard and Hamilton, 1997). In the past two decades, some researchers showed that biological invasion was related to the unique energy-use strategies, especially the leaf construction cost (CC) of an invader (Nagel and Griffin, 2001; Martínez-Garza et al., 2013; Zhu et al., 2015). Construction cost, defined as a measure of the amount of glucose required to produce a unit leaf mass or leaf area (i.e. a glucose equivalent), is a quantitative measurement of the energy invested by a plant to construct a leaf (Williams et al., 1987). In general, low CC is associated with high relative growth rates (Poorter and Villar, 1997; Martínez-Garza et al., 2013; Zhu et al., 2015). However, most of the previous researches on CC focused on terrestrial ecosystems, especially among herbs (Feng et al., 2011; Tu et al., 2013; Wang et al., 2013; Zhu et al., 2015). Little is known about CC in coastal wetland plants. To our knowledge, only two research groups have investigated CC of mangrove species. Suárez (2003, 2005) reported the salinity effect on CC of three mangrove species, *Avicennia germinans*, *Laguncularia racemosa* and *Rhizophora mangle*, but not the importance of CC to invasive potentials. Our group compared the photosynthetic characteristics and CC of two *Sonneratia* species and their adaptation in Shenzhen Futian wetland (Li et al., 2011, 2016) but not the differences in CC of the same species in mangrove wetlands at different geographical locations.

Mangrove ecosystem, a unique intertidal wetland along tropical and subtropical coastlines, has high ecological values, particularly the ecosystem services it provides and the goods that can be extracted from the forest (Duke et al., 2007). However, mangrove forests have been rapidly disappeared in some regions, especially Asia and the Pacific region, where 70% of their original mangrove habitats have been lost

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(Polidoro et al. 2010). To mitigate the habitat loss, mangrove reforestation were initiated in many countries over the past few decades, and alien mangrove plants especially the fast-growing species were introduced to their new habitat (Ellison, 2000). As a consequence, these alien species not only create the risk of replacing the native mangrove species, they may also be invasive. It is important to know the risk of the alien species to local ones, and how the leaf CC affects their invasiveness.

Sonneratia mangrove species, including *Sonneratia caseolaris* (L.) Engl. (Sc) and *S. apetala* Buch.-Ham. (Sa), were purposefully introduced to the lower tidal mudflat areas of Futian Nature Reserve in Shenzhen from Dongzhai Harbor Mangrove Nature Reserve of Hainan Province, China for reforestation projects in the late 1990s (Wang et al., 2002). Sc was a native species in Hainan while Sa was introduced to Hainan from Bangladesh in 1985 but so adaptive to Hainan condition. Both species are known to have fast growth rates and high tolerance to various environmental stresses (Liao et al., 2004). They have also been planted in many other mangrove ecosystems in South China such as Guangdong, Guangxi and Fujian Provinces. The total area of *Sonneratia* (mainly Sa) planted in China reached 3800 ha, accounting for >50% of the replanted mangrove areas in China (Chen et al., 2009, 2015), and had proliferated in 22 counties in Guangdong Province since 2002 (Peng et al., 2016). Since their introduction in China, there have been subjects of debate and disagreements on whether *Sonneratia* should be planted or not, because of their invasive potentials and the possibility of replacing native mangrove species in the ecosystem (Liao et al., 2004). Our previous studies in Shenzhen found that *Sonneratia* had lower CC and higher photosynthetic rate than the native mangrove plants, indicating their invasive potential (Li et al., 2011, 2016). However, it is not clear whether growth and CC of *Sonneratia* after introduced to another mangrove wetland, a new habitat for them, are poorer or better than when they are in the original habitat.

The present study therefore aims to compare the leaf CC and growth traits of *Sonneratia* between Hainan Dongzhai Harbor Mangrove Nature Reserve (where they originally grown) and Shenzhen Futian Mangrove Nature Reserve (where they were introduced), as well as their differences with native mangrove species in both wetlands. The study also attempts to evaluate the invasive potential of the alien *Sonneratia* species after introduced to Shenzhen mangrove wetland. Two *Sonneratia* species (Sc and Sa) and four common and dominant native species, namely, *Bruguiera gymnorrhiza* (L.) Lamk (Bg), *Kandelia obovata* Sheue, Liu et Yong (Ko), *Aegiceras corniculatum* (L.) Blanco (Ac) and *Avicennia marina* (Forsk.) Vierh. (Am) in both mangrove wetlands were selected.

2. Materials and methods

2.1. Study sites

Two mangrove wetlands, namely Dongzhai Harbor Mangrove Nature Reserve (19°54′ N, 110°20′ E) in Haikou City of Hainan Province and Futian Mangrove Nature Reserve (22°31′ N, 114°05′ E) in Shenzhen city of Guangdong Province, were investigated. Both are designated National Nature Mangrove Reserves in China, representing typical natural mangrove ecosystems at two climate zones, tropical and subtropical climates, respectively (Chen et al., 2008). Dongzhai Harbor Mangrove Nature Reserve, in the northeast of Hainan Island, China, is the most well-preserved mangrove forest in China and is one of the most important international wetlands. It is characterized by a tropical monsoonal climate with an annual precipitation of 1685 mm, mean annual air temperature of 23.8 °C (with a low mean monthly temperature of 17.2 °C in January and a high mean monthly temperature of 28.4 °C in July), annual insolation length of day of 2240 h and the seawater salinity of 21.9 (Chen et al., 2008). Futian Mangrove Nature Reserve, located in an estuary of the Zhujiang River in Shenzhen, Guangdong Province, China, is characterized by a subtropical monsoonal climate with an annual precipitation of 1927 mm (Tam et al., 1998; Chen et al., 2008). The mean annual air temperature is 22 °C, with a low mean monthly temperature of 14 °C (in January) and a high mean monthly temperature of 28 °C (in July), and annual insolation length of day of 2209 h and the seawater salinity of <15.0.

2.2. Sample collection and treatment

In each Mangrove Nature Reserve, two *Sonneratia* species (Sc and Sa) and four dominant native mangrove species (Bg, Ko, Ac and Am) were sampled in summer days when plant growth was the highest, which were 25th August in Shenzhen and 5th September in Hainan, to reduce season influences. For each mangrove plant species, three mature healthy trees, each about 10–15 years old, in the centre of the mangrove wetland were randomly sampled. In each tree, 30 fully expanded mature un-shade leaves of similar sizes at different orientations in the canopies were collected and pooled together to form a composite sample. This means the three replicates of each species were made up of 90 leaves. Based on field observations and personal communication with the staff of the Nature Reserves, the three trees of the same species not only had similar ages and growth conditions, the environmental conditions of the sampling areas were also comparable. The leaves were washed with tap water and dried with absorbent paper. The leaf blade area was determined using a leaf area meter (Li-Cor 3100A, Li-Cor, USA) and specific leaf area (SLA) was calculated according to the formula: SLA = Leaf blade area/Leaf weight (Li et al., 2011). After SLA determination, leaves were dried at 70 °C for 72 h, weighed, ground and homogenized into fine powder, then stored in a desiccator to maintain dryness prior to subsequent analyses. The ash-free caloric values (△Hc), nitrogen concentration (N) and ash content (Ash) of the leaf samples were determined and calculated according to standard methods described by Li et al. (2011).

2.3. Determination of leaf construction cost (CC)

The leaf CC per unit of mass (CCM, equivalent to grams glucose per gram dry mass, g(glucose) g^{-1}) was estimated according to the method described by Williams et al. (1987). Even though this method was originally used for calculating CCM of terrestrial plants, Suárez (2003, 2005) used the same method to investigate CCM of three mangrove species (*Avicennia germinans*, *Laguncularia racemosa* and *Rhizophora mangle*) and demonstrated its feasibility on mangrove plants. The CCM was calculated as follows:

$$CCM = {}^{[(0.06968\times\Delta H_c - 0.065)(1-Ash)+7.5(kN/14.0067)]}\Big/_{EG}$$

where *k* was the oxidation state of the N substrate (+5 for nitrate or −3 for ammonium). EG was the growth efficiency and was estimated to be 0.89 across species according to Penning de Vries et al. (1974). The leaf CC based on area (CCA, equivalent to grams glucose per square meter, g(glucose) m^{-2}) was calculated by the formula:

$$CCA = {}^{CCM}\Big/_{SLA}$$

2.4. Data analyses

CC, SLA and other growth traits (△Hc, N and Ash) among the six species in two mangrove wetlands were analyzed using a parametric two-way analysis of variance (ANOVA) with species and wetlands as the sources of variations. If the species effect was significant at $p \le 0.05$, a Student-Newman-Keuls (S-N-K) test for multiple comparisons was used to determine where the difference lies among six species. Differences in CC, SLA and other growth traits of each mangrove species between Hainan and Shenzhen mangrove wetlands were compared by independent sample *t*-test. All data fulfilled the assumptions of the