INVASIVE CAPACITY OF THE MANGROVE *SONNERATIA APETALA* IN HAINAN ISLAND, CHINA

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XIN K, ZHOU Q, ARNDT SK & YANG X. 2013. Invasive capacity of the mangrove *Sonneratia apetala* in Hainan Island, China. The mangrove *Sonneratia apetala* has been introduced into China since 1985 as a plantation species in coastal area. There has been long time speculation regarding the invasive capacity of this species and its contribution to the degradation of native plant communities. In this study, we evaluated in the field the invasive capacity of *S. apetala* by investigating its dispersal, recruitment and regenerative capacity in the Dongzhai Harbour region of Hainan Island, China. Remotely sensed data showed that the total area of *S. apetala* plantings decreased from 20 ha in 1999 to 17.68 ha in 2010. Community investigation data showed that *S. apetala* was the dominant species with 57.3% of average IVI (importance value index) in *S. apetala* communities, while its natural regeneration did not occur at regular intervals. The seedling dispersal analysis revealed that individuals of *S. apetala* did not prevent seedlings of other species from establishing, indicating that *S. apetala* did not keep other species from growing into mangrove communities. Meanwhile, no evidence was found to show that *S. apetala* was an invasive species competing with the native species. On the contrary, *S. apetala* acted primarily as a pioneer tree species in the coastal environments of Hainan Island.

Keywords: Community structure, invasion, seedling regeneration, rehabilitation

XIN K, ZHOU Q, ARNDT SK & YANG X. 2013. Keupayaan invasif bakau *Sonneratia apetala* di Pulau Hainan, China. Bakau *Sonneratia apetala* diperkenalkan di China sejak 1985 sebagai spesies ladang di kawasan pantai. Sejak sekian lama, terdapat spekulasi tentang keupayaan invasif spesies ini dan peranannya terhadap degradasi komuniti tumbuhan tempatan. Dalam kajian lapangan ini, kami menilai keupayaan invasif *S. apetala* dengan menyiasat penyebaran, perekrutan dan keupayaan penjanaan semula spesies ini di kawasan Pelabuhan Dongzhai yang terletak di Pulai Hainan, China. Data penderiaan jauh menunjukkan penanaman *S. apetala* menurun daripada 20 ha pada tahun 1999 ke 17.68 ha pada tahun 2010. Data siasatan komuniti menunjukkan bahawa *S. apetala* merupakan spesies dominan dengan purata indeks nilai kepentingan (IVI) sebanyak 57.3% dalam komuniti *S. apetala*. Sebaliknya, penjanaan semula spesies ini secara semula jadi tidak berlaku secara tetap. Analisis penyebaran anak benih menunjukkan bahawa individu *S. apetala* tidak menghalang anak benih lain tumbuh dalam komuniti bakau. Dalam pada itu, tiada bukti yang menunjukkan bahawa *S. apetala* merupakan spesies invasif yang bersaing dengan spesies tempatan. Sebaliknya, *S. apetala* bertindak sebagai spesies pokok perintis di persekitaran pantai Pulau Hainan.

INTRODUCTION

Mangrove wetlands are important coastal ecosystems that provide a range of essential ecosystem services such as habitat and nursery for wildlife and marine animals, maintenance of marine water quality, protection of coastlines and coastline developments. However, human activities and economic developments in coastal regions have put extreme strain on coastal ecosystems and have already resulted in significant losses of coastal wetlands (Arghya et al. 2009). To rehabilitate wetlands, mangrove species with high survival rates have been introduced into the original wetland communities (Chen et al. 2003, Harun-or-Rashid et al. 2009).

However, some introduced mangrove species caused serious alien species invasion and threatened the survival of local mangrove

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species (Fourqurean et al. 2010). These invasive species changed the mangrove community structure (Manna 2010), decreased the biodiversity (Donnelly et al. 2008, Demopoulos & Smith 2010), impaired ecosystem functions (Bosire et al. 2005) and influenced biological evolution (Anderson et al. 2010, Sweetman et al. 2010).

The mangrove *Sonneratia apetala* (Sonneratiaceae) is a woody mangrove species. The height of this species ranges from 15 to 20 m and its diameter at breast height (dbh) varies between 20 and 30 cm (Kairo et al. 2009). The species is naturally distributed in India, the Bengal region and Sri Lanka as a dominant species in local mangrove communities (Liao et al. 2004). *Sonneratia apetala* is highly adaptable, fast growing and is used as a pioneer species in ecological succession in many degenerated mangrove forests (Chen et al. 2003). Due to its high adaptability and seed production capacity, it has been utilised for restoration purposes in many other places besides its original locations (Ren et al. 2009, Fourqurean et al. 2010). *Sonneratia apetala* was planted in China in 1985 and has become an important species for degraded mangrove forests restoration (Zhang et al. 2011). This species is widely used in many areas in mainland China, particularly in Hainan Island, for restoring degraded coastal mangrove areas. It has led to the successful reclamation of many degraded mangrove forests by modifying site conditions and facilitating the survival and establishment of native species (Zan et al. 2003).

However, there are some concerns about the negative impacts of *S. apetala* on the native plant community structure in rehabilitated mangrove ecosystems which could lead to ecological problems in the future (Ren et al. 2009). Many concerns were related to its high growth rate (39.4% greater height and 26.5% greater dbh compared with the native *Sonneratia caseolaris*) (Li 1996) and reproductive capacity (Li et al. 2010). Laboratory studies conducted using aqueous extracts of different parts of *S. apetala* revealed apparent allelopathic effects on native mangrove species (Li et al. 2004). However, a study of *S. apetala* and the indigenous species in Shenzhen Bay, China showed that their niches did not overlap, suggesting that the former was unlikely to pose any ecological threat to the latter (Zan et al. 2003). An ecological impact analysis in the Jiulong River Estuary also concluded that *S. apetala* did not initiate any biological invasion (Pan et al. 2006).

Despite serious concerns over the invasive capacity of *S. apetala*, except for the few laboratory evidences, no field studies have been conducted to investigate the impact of its plantings on native plant communities. Therefore, the main objective of the current study was to evaluate the invasive capacity of *S. apetala* in the field. The Dongzhai Harbour area in Hainan Island, China was selected as the study area, where *S. apetala* was first planted in 1985. It is an ideal location to study the long-term ecological impacts of *S. apetala*. The study consisted of three parts: (1) the distribution of *S. apetala* between 1999 and 2009 in the study region were compared to investigate if the plantations had spread beyond the initial planted area; (2) the community composition and age structure of *S. apetala* plantings were analysed and the age of native plants in the study region determined to ascertain the impacts of *S. apetala* on biodiversity; and (3) the composition of newly established seedlings was measured to evaluate the influences of *S. apetala* on recruitment.

MATERIALS AND METHODS

Study site

The study area, Dongzhai Harbour, is located north-east of Hainan Island, China and lies between 110° 30' and 110° 37' E and 19° 51' and 20° 01' N (Figure 1). Mangrove forest covers about 1858 ha of the area (Kun 2009). The area contains 95% of the mangrove species that occur in China (Lin 1997). Its rich biodiversity and the extent of coverage make it the most important mangrove area in the country. The mangrove species found here belong to 19 plant families and 35 species among which, 11 families and 25 species are true mangroves while 9 families and 10 species are semi-mangrove (Lin 1997).

Before 1985, the embryonic axes of *S. apetala* were introduced into the study area from Bangladesh. The purpose was to protect the coastline and to facilitate the recovery of

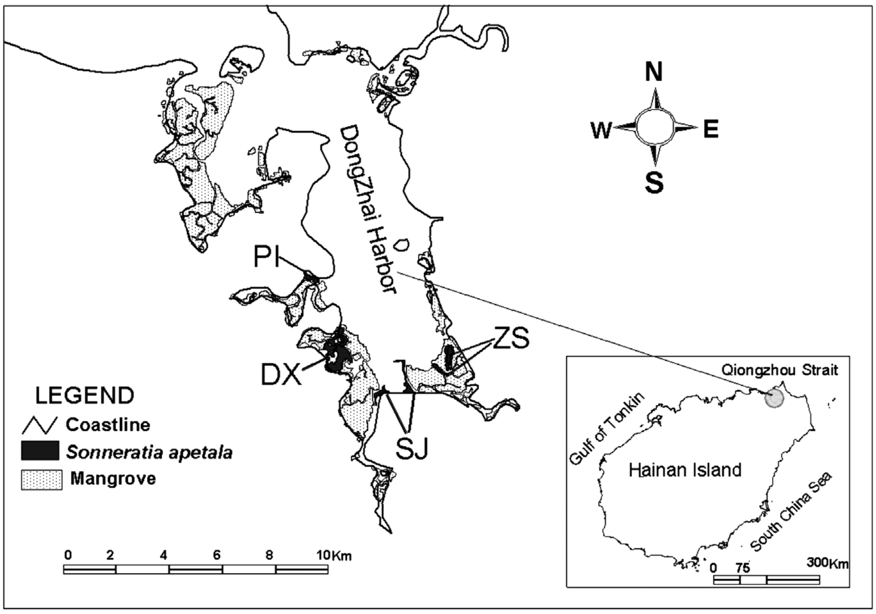

Figure 1 Distribution of *Sonneratia apetala* in the Dongzhai Harbour region of Hainan Island of China in 2009; light grey areas indicate distribution of other mangroves and dark grey areas indicate occurrence of *S. apetala*; letters indicate the location of study plots: Dao Xue (DX), San Jiang (SJ), Zhu Shan (ZS) and Yeboluo Island (PI) ('Yeboluo' is Chinese for *Pandanus tectorius*)

declined mangrove forests. *Sonneratia apetala* seeds were cultivated in the seedling beds on the beach. After several months, seedlings greater than 60 cm in height were planted into the fields in 1985.

Four sites were selected as the planting areas in Hainan Island: Dao Xue (DX), San Jiang (SJ), Zhu Shan (ZS) and Yeboluo Island (*Pandanus tectorius* Island) (PI). The last site is located among several tidal channels and is constantly affected by periodic tide and touring ship propelling. All other sites were severely impacted by farming actives (Kun 2009).

Distribution of *Sonneratia apetala*

High spectral resolution images were utilised to map the distribution of individual species. The spectral information provided by hyperspectral sensors was used to detect invaders at the species level across a range of community and ecosystem types (Hestir et al. 2008, Altamirano et al. 2010).

Sonneratia apetala is taller and has bigger crown compared with many local species such as *Kandelia obovata, Aegiceras corniculatum, Ceriops tagal* and *Bruguiera gymnorrhiza* (Wang 2008). As a result, *S. apetala* possesses unique reflectance properties, allowing it to be distinguished from other species via spectrum synthesis. In this study, the 2009 Quickbird images of 0.6-m spectral resolution and the 2008 Iknos images of 1-m spectral resolution were adopted. The image analysis results were validated via field studies. From the field investigation, *S. apetala* distribution in 2008 and 2009 were studied by first being mapped into ARCGIS 9.2 (see the dark area in Figure 1), followed by subsequent *S. apetala* area calculation. The original *S. apetala* distribution (in 1999) was digitised by transferring the planting map (provided by Dongzhai Harbour Forest Management Bureau) into a digital map using Arcview 3.3. By comparing the difference between the present and original distribution, the spatial variation in *S. apetala* population was assessed using ArcGIS.

Community structure analysis

From 2009 till 2010, 30 quadrats (each 10 m × 10 m) were randomly selected at the four sites where *S. apetala* was originally planted (Figure

1). Individuals were identified and counted for each species. Diameter of breast height and the height of each individual were recorded in each quadrat.

The importance value index (IVI) of each species in the community was calculated using the equation by Curtis (1951):

$$IVI = \frac{Dr + Cr + Pr}{3} \quad (1)$$

where Dr is the relative density, Cr is the relative cover degree and Pr is the relative dominance. The relative dominance was determined by (Makoto 1961):

$$Pr = Dr + Cr + Fr + Hr \quad (2)$$

where Fr and Hr are the relative frequency and the relative height respectively.

The age structure of communities can be utilised to analyse the evolution dynamics and trends of plant communities. In this study, the age structure was categorised into five levels according to the dbh and height of individual plant (Ahmed et al. 2010):

Age 1: dbh < 2.5 cm, h < 0.33 m
Age 2: dbh < 2.5 cm, h > 0.33 m
Age 3: dbh 2.5–7.5 cm
Age 4: dbh 7.5–22.5 cm
Age 5: dbh > 22.5 cm

Based on spatial distribution of the age structure, the development of *S. apetala* communities can be quantitatively evaluated at the different sites.

Seedling regeneration

The invasive characteristics of *S. apetala* can be assessed by studying its seedling regeneration in the study area. The seeding regeneration was investigated by selecting 44 mature *S. apetala* individuals (mature individuals can produce healthy plumular axis which can survive in suitable environment) and placing two 1 m × 1 m quadrats under each adult tree. In each quadrat, the species type, number and height of each seeding as well as its distance to the adult *S. apetala* tree were recorded. The abundance of each seedling species as well as its distance to the adult *S. apetala* tree were compared to identify the allelopathy influences that affected the seedlings from the *S. apetala* trees and evaluate the difference in regeneration abilities between *S. apetala* and other species.

Statistical analyses

SPSS and Excel were employed in data analyses. The community structure characteristics were analysed using one-way analysis of variance (ANOVA) followed by subsequent t-test. The analysis of the age structure and regeneration of *S. apetala* were conducted using Excel.

RESULTS

The distribution of *S. apetala* community

From the spectral resolution images, mangroves were distinguished from other landuses by both automatic and manual interpretation in ENVI 4.0 (Figure 1). The total mangrove forest area in the study area was about 1858 ha. Mangrove communities containing *S. apetala* covered a total area of 17.68 ha in the study area, i.e. 8.61 ha in Dao Xue, 4.73 ha in San Jiang, 3.25 ha in Zhu Shan and 1.09 ha in Yeboluo Island. The total *S. apetala* plantation area in 1999 was about 20 ha with 8.8 ha in Dao Xue, 6.0 ha in San Jiang, 4.2 ha in Zhu Shan and 1.0 ha in Yeboluo Island (Anonymous 2000). Through comparison with the data in the year 2009, we found that the area where *S. apetala* occurred was reduced by 2.2–21.2% from 1999 till 2009 in Dao Xue, San Jiang and Zhu Shan. The exception was Yeboluo Island where *S. apetala* area increased by 9%.

Community structure of *S. apetala*

Eleven species were recorded in the *S. apetala* communities in Dao Xue, San Jiang, Zhu Shan and Yeboluo Island. The structure analysis of the plant communities indicated that *S. apetala* was the dominant plant species at all four study sites. Specifically, *S. apetala* in Dao Xue, San Jiang and Zhu Shan had the greatest dbh and crown diameter ($F = 21.5$, $df = 10$, $p < 0.05$), while at the Yeboluo Island, it was the only species recorded (Table 1). Since the community structure in the Yeboluo Island site was not controlled by natural processes, it was not considered in the IVI analysis. At the Dao Xue and San Jiang sites where *S. apetala* was predominant, many other species were also observed but they were generally smaller. *Sonneratia caseolaris* and *S. apetala* at these two sites had similar height and dbh but the abundance of the former was much lower. At the Zhu Shan site, many *S. apetala* trees were over 9 m, but on average, *S. caseolaris* was the tallest (11 m) and widest (dbh = 33 cm). With wider mud flat, small seedlings distribute widely in Zhu Shan. Seedlings of *Acanthus ilicifolius* and *Aegiceras corniculatum* could be found here with densities of 275 ha^{-1} and 8925 ha^{-1} respectively.

Sonneratia apetala had significantly ($F = 21.5$, $df = 10$, $p < 0.001$) the highest IVI followed by *S. caseolaris, K. obovata* and *A. corniculatum* (Figure 2). The lowest IVI was observed for *Lumnitzera littore* which was only present in Dao Xue.

Age structure of communities

Among the five age categories, age 1, in which plant age was the smallest, had the most species (11 species), followed by ages 2 and 3 (both had 7 species). The most common species found in ages 1, 2 and 3 categories were *K. obovata* and *A. corniculatum* while other native species such as *Bruguiera sexangula, Excoecaria agallocha, Avicennia marina, A. ilicifolius* and *L. littorea* were also observed. In contrast, ages 4 and 5 categories comprised only two species, namely, *S. apetala* and *S. caseolaris* (Figure 3).

Seedling distribution

Seedlings of 10 species were observed in the 1 m × 1 m quadrats under the *S. apetala* adult trees. The dominant species were *A. corniculatum, S. apetala* and *K. obovata* (Figure 4).

Table 1 Composition and structural estimates of plant communities in the four study plots in the Dongzhai Harbour region of Hainan Island of China

Site	Species	Density (per ha)	Average height (m)	Average dbh (cm)	Average crown diameter (m)
DX	*Sonneratia apetala*	762 ± 146	9.0 ± 7.2	13.0 ± 11.0	3.2 ± 2.5
	Bruguiera sexangula var. *rhynchopetala*	100 ± 18	1.4 ± 0.3	-	-
	Aegiceras corniculatum	275 ± 79	1.0 ± 0.2	-	-
	Bruguiera gymnorrhiza	75 ± 6	1.5 ± 0.2	1.3 ± 0.1	0.6 ± 0.2
	Lumnitzera littore	213 ± 95	2.4 ± 0.4	3.3 ± 0.2	1.1 ± 0.3
	Sonneratia caseolaris	100 ± 22	8.0 ± 6.8	41.0 ± 39.0	2.9 ± 2.5
	Kandelia obovata	225 ± 51	1.6 ± 0.8	0.5 ± 0,1	0.4 ± 0.1
	Excoecaria agallicha	25 ± 11	4.0 ± 0.5	4.7 ± 0.1	1.8 ± 0.1
ZS	*Sonneratia apetala*	150 ± 42	9.0 ± 6.9	21.0 ± 19.0	3.3 ± 2.7
	Acanthus ilicifolius	525 ± 131	-	-	-
	Sonneratia caseolaris	75 ± 19	11.0 ± 9.2	33.0 ± 31.0	2.7 ± 2.4
	Kandelia obovata	625 ± 203	3.0 ± 1.7	2.8 ± 0.2	0.8 ± 0.6
	Aegiceras corniculatum	8925 ± 1400	1.3 ± 0.2	-	-
	Avicennia marina	275 ± 48	1.5 ± 0.3	-	-
SJ	*Sonneratia apetala*	1187 ± 311	12.0 ±	18.0 ± 16.0	3.1 ± 2.5
	Bruguiera sexangula	67 ± 11	2.1 ± 1.0	1.3 ± 0.1	0.6 ± 0.3
	Aegiceras corniculatum	47 ± 20	2.2 ± 0.4	1.6 ± 0.2	0.5 ± 0.1
	Bruguiera gymnorrhiza	20 ± 4	2.5 ± 0.2	1.2 ± 0.1	0.4 ± 0.1
	Bruguiera sexangula var. *rhynchopetala*	20 ± 6	2.2 ± 0.6	1.2 ± 0.3	0.6 ± 0.2
	Sonneratia caseolaris	27 ± 5	9.0 ± 4.6	12.0 ± 7.0	2.2 ± 1.9
	Kandelia obovata	200 ± 46	2.0 ± 0.5	1.7 ± 0.7	0.5 ± 0.3
PI	*Sonneratia apetala*	700	13.0 ± 7.7	53.0 ± 48.0	3.5 ± 2.5

Mean values in the same column are significantly different at $p < 0.05$; - = wood was too small to record its dbh and crown diameter; DX = Dao Xue, ZS = Zhu Shan, SJ = San Jian, PI = Yeboluo Island

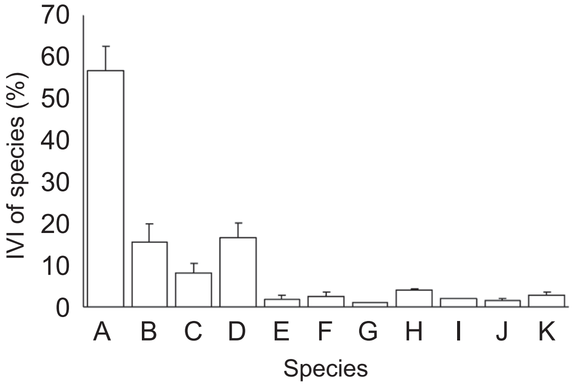

Figure 2 Importance value index (IVI) in per cent for different species in the Dongzhai Harbour region of Hainan Island China; different letters represent the following species: A = *Sonneratia apetala*, B = *Kandelia obovata*, C = *Aegiceras corniculatum*, D = *Sonneratia caseolaris*, E = *Bruguiera sexangula*, F = *Bruguiera gymnorrhiza*, G = *Bruguiera sexangula* var. *rhynchopetala*, H = *Excoecaria agallicha*, I = *Avicennia marina*, J = *Acanthus ilicifolius*, K = *Lumnitzera littore*; error bars show standard errors

Sonneratia apetala seedlings were dominant in the quadrats near the water front while *A. corniculatum* seedlings were dominant in the inland quadrats. Average seedling distance to the adult *S. apetala* was 0.95 m with minimal distance of 0.1 m. *Kandelia obovata* was most commonly observed and accounted for 88% of all seedlings.

DISCUSSION

Changes in distribution of *S. apetala*

Survival rates of *S. apetala* at all study sites were less than 9% (Li 1996). As a result, new seedlings were constantly planted to compensate for the losses. Since 1999, with better understanding of seedling ecology, taller and older seedlings of *S. apetala* (> 70 cm in height at the time of planting) were used in the replanting programmes, which significantly increased the survival rate from 9 to 90–98%

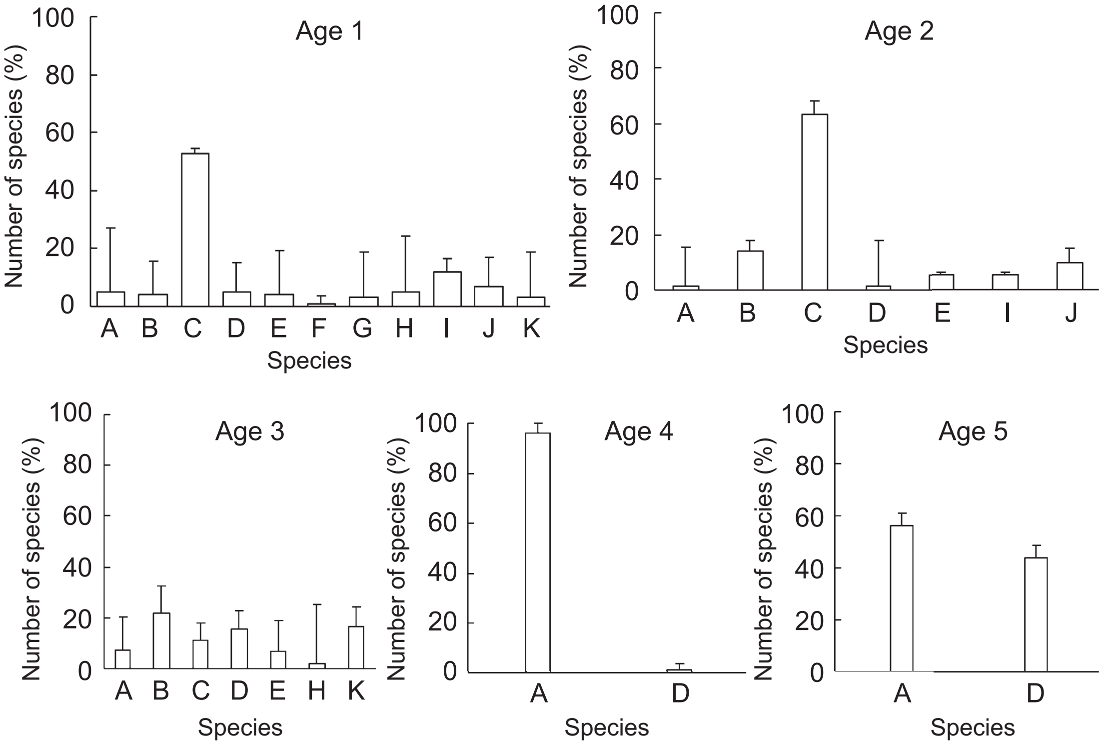

Figure 3 Distribution of different mangrove species in different age classes in the Dongzhai Harbour region of Hainan Island of China; the age classes were defined as follows: age 1: dbh < 2.5 cm, h < 0.33 m; age 2: dbh < 2.5 cm, h > 0.33 m; age 3: dbh 2.5–7.5 cm; age 4: dbh 7.5–22.5 cm; age 5: dbh > 22.5 cm; different letters represent the following species: A = *Sonneratia apetala*, B = *Kandelia obovata*, C = *Aegiceras corniculatum*, D = *Sonneratia caseolaris*, E = *Bruguiera sexangula*, F = *Bruguiera gymnorrhiza*, G = *Bruguiera sexangula var. rhynchopetala*, H = *Excoecaria agallicha*, I = *Avicennia marina*, J = *Acanthus ilicifolius*, K = *Lumnitzera littore*; error bars show standard errors

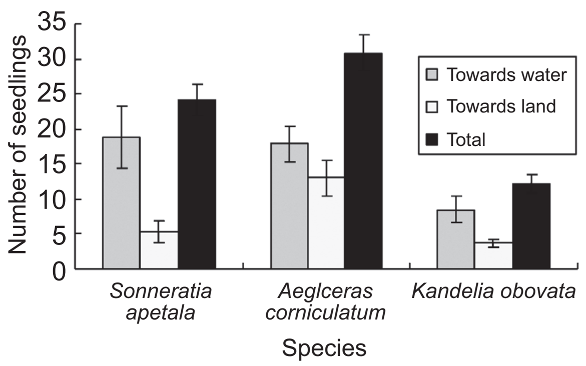

Figure 4 Average seedling numbers of the three main species under mature *S. apetala* trees in the Dongzhai Harbour region of Hainan Island of China; error bars show standard errors

(Liao et al. 2004). The total planting area in 1999 was approximately 20 ha, while the distribution area at present was about 17.68 ha. Clearly, except for Yeboluo Island where *S. apetala* was replanted every year because the bank was constantly damaged by tour boats which led to the slight increase of *S. apetala* by 9%, *S. apetala* remained within its original planting area and did not spread outwards. The areas in Dao Xue, San Jiang and Zhu Shan decreased by 2–20% from 1999 till 2009. These results proved that *S. apetala* was not an invasive species.

Community structure

The non-invasive characteristics of *S. apetala* were also confirmed by results of the community structure analysis. Particularly, as revealed by the IVI analysis, although *S. apetala* was the dominant species in the planted areas, it was no longer the dominant species among the younger seedlings, i.e. the species belonging to age categories of 1, 2 and 3. This indicated that the propagule production for *S. apetala* was quite low and less new cohorts of the plants was established. It has been reported that in Futian mangrove (another mangrove reserve in southern China), *K. obovata* took 8 years to become dominant while *A. corniculatum*, 9–10 years (Chen et al. 2003). However, *S. apetala* and *S. caseolaris* in Futian achieved dbh values of 12.9 and 9.5 cm respectively within only 5 years (Chen et al. 2004b). This showed that most native species grew slower than *S. apetala*. However, it is reasonable to expect that the native species will increasingly become more dominant in the planted areas in the future. Our community investigation results showed that the highest number of *S. apetala* trees was found in the age 4 category, which was most likely due to the extensive planting in 1999.

The Dao Xue, San Jiang and Zhu Shan sites are agriculture regions where aquaculture and farming activities destroy huge areas of native mangrove forests. The bare mud flat provided enough space and light for the replanted *S. apetala* to survive and consequently, the survival rates of *S. apetala* at these three sites were about 90–98%. Other species, such as *Cerriops decandra, B. gymnorrhiza, K. obovata, Rhizophora stylosa, A. marina* and *A. corniculatum* were also able to germinate and grow within the *S. apetala* communities formed several years before. The Yeboluo Island site, on the other hand, is a tourism area in which the yachts propel the water and erode the bank. As a result, it was difficult for seeds to naturally settle into the ground. *Sonneratia apetala,* therefore, became the only species that survived at the site.

Allelopathic and regeneration ability of *S. apetala*

Negative allelopathic effects exerted by *S. apetala* on other species including *B. gymnorrhiza, K. obovata, A. marina* and *A corniculatum* have been reported in glasshouse experiments (Li et al. 2004). However, similar effects were not fully observed in this study. Under adult *S. apetala* trees, seedlings of native species could be seen very commonly. Among these seedlings, *A. corniculatum* and *K. obovata* were more abundant than *S. apetala* seedlings, indicating that *S. apetala* did not suppress the germination and/or establishment of seedlings of the other species.

Seedlings of *A. corniculatum, S. apetala* and *K. obovata* were the most common under the *S. apetala* adult trees. *Aegiceras corniculatum* was the most abundant species at the most inland sites, which was consistent with results of a study of the vigorous regeneration ability of this species during seedling period (Chen et al. 2004b). At sites near the water front, seedlings of *S. apetala* and *A. corniculatum* had similar abundance, indicating the greater capacity of the former to endure the periodic tide and the exceptional strong winds from sea surface.

Invasive capacity of *S. apetala*

Our results proved that *S. apetala* had low invasive potential in the study area. The species had high growth and germination rates in areas without competition from other species. However, once established, this species did not invade and dominate over other mangrove species. On the contrary, it changed the microenvironment of the soil, hydrology and illumination, which benefited other mangrove species to settle and grow. Consequently, seedlings of other species were able to establish in the original *S. apetala* plantations. *Sonneratia apetala* is highly successful in regenerating degraded mangrove forests by facilitating the recolonisation of native mangrove species during the early stages of community formation and improving the site and edaphic conditions (Ren et al. 2009). Results of the plant community composition showed that many species inhabit the former *S. apetala* plantations at various growth stages. In contrast, *S. apetala* occurred almost exclusively in older age categories, confirming that they did not regenerate well under the non-pioneer conditions. A similar phenomenon was also observed in a mangrove forest study conducted in Shenzhen Bay in China, in which *S. apetala* could not replace the native mangrove species in the middle or high tidal flats (Zan et al. 2003). The authors concluded that *Sonneratia* spp. required light for germination and their seedlings had low shade tolerance which would make it unlikely for them to self-regenerate in existing mangrove forests.

There are still some concerns that *S. apetala* is a highly invasive species in other regions of China (Ren et al. 2009). However, the reasons behind the increased distribution were not investigated in detail and, in many cases, might be ascribed to the active planting of the species (Chen et al. 2004a). The present study provided conclusive evidence that the invasive capacity of *S. apatala* is rather limited in the study area. To assess the real invasive potential of *S. apatala*, it will be necessary to conduct similar studies in other areas planted with *S. apetala* since 1985.

CONCLUSIONS

Since its introduction into Dongzhai Harbour, Hainan, *S. apetala* has become the dominant species in the original planted areas. The establishment of *S. apetala* plantations facilitated the recovery of the mangrove communities; local mangrove species were frequently found in the recovered communities. Although there were concerns that the introduced plants could cause serious alien plant invasion, our study clearly demonstrated that *S. apetala* was not invasive in the study area. *Sonneratia apetala* did not spread beyond the area that was originally planted and did not prevent local species from establishment or spreading. In contrast, the very fact that the local species were the most abundant seedlings found in *S. apetala* plantations confirmed that *S. apetala* could be successfully utilised as a pioneer species to recover degraded mangrove communities.

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