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Aquatic Botany 74 (2002) 315–325

**Aquatic
botany**

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The effect of increasing sediment accretion on the seedlings of three common Thai mangrove species

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Received 4 January 2002; received in revised form 11 July 2002; accepted 22 August 2002

Abstract

Three to four-month-old seedlings of three common Thai mangrove species (*Avicennia officinalis* L., *Rhizophora mucronata* Lamk and *Sonneratia caseolaris* (L.) Engler) were experimentally buried using six sediment accretion levels (0, 4, 8, 16, 24 and 32 cm) in a randomized block design. *Avicennia* was five-fold more sensitive to burial than *Sonneratia* and the seedlings of the latter species exhibited the lowest mortality as well as the highest growth rate. The numbers of surviving seedlings of these two species were highly affected by burial ($P < 0.001$) and their survival decreased with increasing sediment accretions. The seedlings receiving 32 cm of sediment had the highest mortality (100% in *Avicennia*, 70% in *Rhizophora* and 40% in *Sonneratia*). Survival of *Rhizophora*, however, was not significantly different amongst treatments ($P = 0.23$). Natural mortality in the control seedlings was substantial in *Avicennia* and *Rhizophora* (10 and 40%, respectively). Burial had significant effects on seedling height in *Avicennia* and *Sonneratia* only ($P < 0.05$). The relative growth rate in terms of height was lowest in the 32 cm treatment in both species: 0.30 ± 0.19 and 1.20 ± 0.11 mm cm⁻¹ per month, respectively, compared to 1.15 ± 0.15 and 1.28 ± 0.09 mm cm⁻¹ per month in the controls. Annual internode production declined significantly with burial depth in *Avicennia*, whereas, it increased in *Sonneratia*. Although seedling survival of *Rhizophora* was not significantly affected by different sediment levels, the overall survival of this species was much lower than that of *Sonneratia*. The results reveal that *Sonneratia* will be better suited for colonizing or being planted in areas potentially subject to abrupt high sedimentation.

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Keywords: Mangrove; Sediment; Burial; *Avicennia*; *Rhizophora*; *Sonneratia*; SE Asia

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1. Introduction

Mangroves are common inhabitants of tropical sheltered mud flats, lagoons and deltas. The adult trees of many mangrove species have distinctive aerial roots with a well-developed system of interconnected lacunae and lenticels that store and transport oxygen inside the plant (Tomlinson, 1986; Hutchings and Saenger, 1987; Ashford and Allaway, 1995). Aerial roots are generally recognized as an adaptation to cope with the oxygen deficiency and reduced conditions which render a number of soluble phytotoxins such as Fe^{2+} , Mn^{2+} , and H_2S (McKee, 1993; Youssef and Saenger, 1996, 1998). In young seedlings whose aerial roots have not yet been developed, lenticels are conspicuous on hypocotyl, stem and internodes such as in *Rhizophora* and *Avicennia* (Ashford and Allaway, 1995; Youssef and Saenger, 1996). During high tide, these lenticels are covered with water preventing gas exchange through their aerial vents. Tidal submergence may cause short-term oxygen shortage in the roots, particularly during night time, but subsequent low tide emergence will re-establish atmospheric contact and resume root aerobic respiration. The venting role of the lenticels is, however, impaired if they are covered by sediment. Tropical rivers carry massive amounts of sediments during the rainy season (Milliman and Meade, 1983) which are discharged into coastal waters, frequently as sudden high-sedimentation events. Such events can cause extensive burial of the mangrove aerial roots, inhibit root aeration, and consequently, lead to widespread mortality (Hutchings and Saenger, 1987; Ellison and Farnsworth, 1993, 1996). A number of accounts on impacts of sedimentation on mangroves have been compiled recently by Ellison (1999). However, relevant quantitative data on SE Asian mangrove species are rare and particularly those on seedlings which might be more sensitive to burial than adult trees (Terrados et al., 1997).

The aim of this study is to examine the effects of experimental sediment burial on seedlings of three common SE Asian mangrove species: *Avicennia officinalis* L., *Sonneratia caseolaris* (L.) Engler and *Rhizophora mucronata* Lamk. The first two species have been considered as pioneer species colonising newly accreting mud flats (Tomlinson, 1986; Lee et al., 1996; Panapitukkul et al., 1998) and the last is a dominant, late successional species widely used for rehabilitation programs (Field, 1995; Havanond, 1995). Knowledge of species-specific sensitivities to sedimentation will provide a better understanding of natural processes of space occupation by mangroves (i.e. colonization on new habitats, recovery after perturbation) which is useful for planning of more successful mangrove rehabilitation schemes (Havanond, 1995; Elster, 2000).

2. Materials and methods

The study was conducted at the edge of the mangrove forest in Songkhla Lake, Songkhla province, Southern Thailand. Songkhla Lake comprises of three connected lakes with the total area of 987 km². The lakes are shallow (1–2 m depth) except in the navigation channels (4–7 m). Tides are mixed-diurnal and the tidal level varies between 0.1 and 0.6 m. Two distinct climatic periods occur; a short dry period (February–May) and a long rainy period with the SW monsoon (May–September) and the NE monsoon (October–January). Spatially, salinity ranges between 20 and 28 ppt during the dry season and 0–14 ppt during the rainy

season. Annual mean temperature is 28 °C and average rainfall is 2150 mm. Many canals carrying suspended sediments from various sources discharge into the lake. During the rainy season, huge amounts of sediment are deposited and accumulate in the area (496,000 m³ per year: Harbor Department, 1996). Mangrove fringes are present discontinuously along the eastern bank of the lake. *S. caseolaris* and *Nypa fruticans* are abundant in the upper part of the lake whilst some *A. officinalis* mixed with *Rhizophora apiculata* and *R. mucronata* occupy the lower part.

The experiment was set-up at the mangrove forest edge near the Hua Khao community participatory rehabilitation area (7°11'N, 100°33'E), 6 km from the mouth of the Lake. The soil of the area is composed of 22–30% clay and 28–31% silt. Between 3- and 4-month-old seedlings of *A. officinalis*, *R. mucronata* and *S. caseolaris*, with average heights of 46 ± 2, 77 ± 1 and 36 ± 1 cm, respectively, were transplanted with 1.5 m × 1.5 m spacing in May 1999. This one month difference in age among the seedlings of the three species is limited since it corresponds to only one internode for *Avicennia* and *Rhizophora* and two internodes for *Sonneratia* (Duarte et al., 1999). *Avicennia* and *Sonneratia* seedlings were obtained by shoveling natural seedlings available in the area while *Rhizophora* seedlings were obtained from the community's nursery. A randomized block design with five blocks was applied for 60 seedlings of each species. After transplanting, the seedlings were allowed to recover for 3 weeks before being buried with sediment. In each block, six sediment burial levels (0, 4, 8, 16, 24, 32 cm) with two replicates were assigned randomly to the seedlings. Sediment burial was realized with PVC cylinders (30 cm in diameter) of different height encircling individual seedlings. Each cylinder was inserted 10 cm into the substratum and the remaining height was equal to the thickness of sediment burial assigned to each individual. All cylinders were then filled with nearby available sediment and two bamboo sticks were inserted at the outer opposite sides of each cylinder. The effect of burial on the seedlings was assessed by quantifying seedling growth and mortality. Measurement of seedling height and number of internodes on the main stem was conducted at the initiation of the experiment and for approximately 1 year with 3-month intervals. The effect of sediment burial on seedling survival was assessed using a factorial ANOVA with blocks as replicates. Besides, seedling loss affected by time and sediment burial was quantified using the non-linear regression model as survivors = $a + b_1 \times \text{time} + b_2 \times \text{burial} \times \text{time}$, where b_1 is a daily loss rate with time and b_2 is an increase in daily loss rate per cm of sediment burial (Terrados et al., 1997). Because of a slight difference in initial seedling sizes, data on seedling height were translated into relative growth rate (Hunt, 1982). An ANOVA with repeated measures design (Potvin et al., 1990) was applied for the examination of burial effect on seedling growth both in terms of relative growth rate and internode production since the same seedlings were monitored on consecutive samplings.

3. Results

Mortality was limited in the first 1–2 months, but thereafter the three species displayed different survival patterns as a function of burial (Fig. 1): *Sonneratia* exhibited a lower mortality than *Avicennia* and *Rhizophora*. The number of surviving seedlings differed significantly amongst sediment burial levels in *Avicennia* and *Sonneratia* ($P = 0.000$; Table 1,

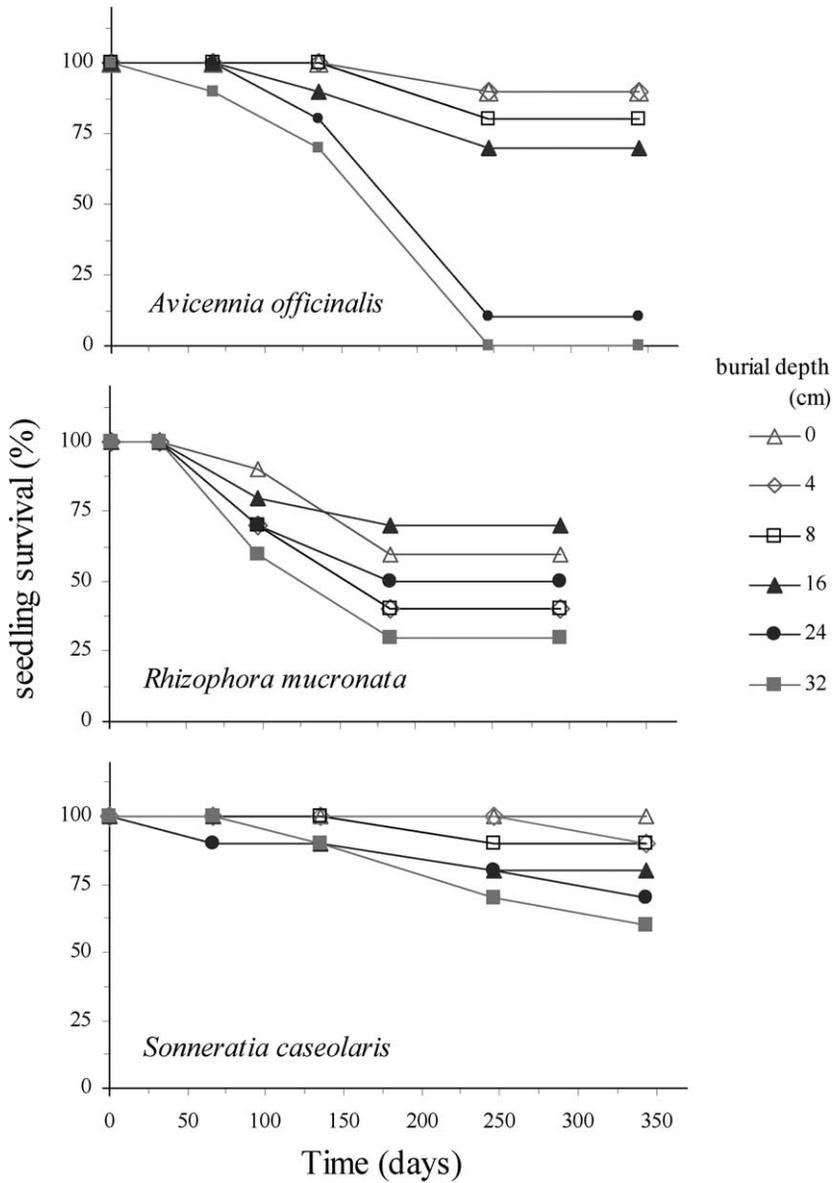


Fig. 1. Seedling survival (%) over the experimental period of the three species as a function of sediment burial. Legend gives burial depth (cm).

Fig. 1). The survival curves of *Avicennia* seedlings receiving 4 cm of sediment and the controls (0 cm) were similar and their mortality after 1 year was low (10%; Fig. 1). The seedlings receiving 8 and 16 cm treatments followed the same pattern but suffered a somewhat higher mortality (20 and 30%, respectively, after 1 year). Survival of *Avicennia* was limited at

Table 1

Three way ANOVA examining the effects of sediment burial on seedling survival after 1 year for *A. officinalis*, *R. mucronata* and *S. caseolaris*

Factors	<i>Avicennia</i>			<i>Rhizophora</i>			<i>Sonneratia</i>		
	d.f.	SS	<i>P</i>	d.f.	SS	<i>P</i>	d.f.	SS	<i>P</i>
Treatment	5	18.8	0.000	5	3.0	0.230	5	2.4	0.000
Block	4	1.4	0.490	4	5.6	0.013	4	0.6	0.196
Treatment × block	20	5.6	0.840	20	8.0	0.527	20	4.6	0.001
Residual	120	50.0		120	50.8		120	11.2	
Total	149	75.8		149	67.4		149	18.8	

Presented are the degrees of freedom (d.f.), sums of squares (SS) and level of significance (*P*).

higher burial levels: only 10% remained alive under 24 cm, whereas, all had died under 32 cm already after 8 months (Fig. 1). In *Rhizophora*, the number of surviving seedlings declined evenly in all treatments as the experiment progressed. In the controls of this species, the final survival was 60%, whereas, under 4 and 8 cm of sediment this was 40% and only 30% under 32 cm (Fig. 1). The ANOVA analysis, however, failed to detect significant differences between burial levels (*P* = 0.230; Table 1). The seedlings of *Sonneratia* survived better than those of the other two species with no mortality in the controls and the seedlings buried with 4 and 8 cm of sediment suffered only 10% mortality. Furthermore, survival at the end of the experiment under 32 cm burial level was 60%, which is considerably higher than that shown by *Avicennia* and *Rhizophora* (Fig. 2).

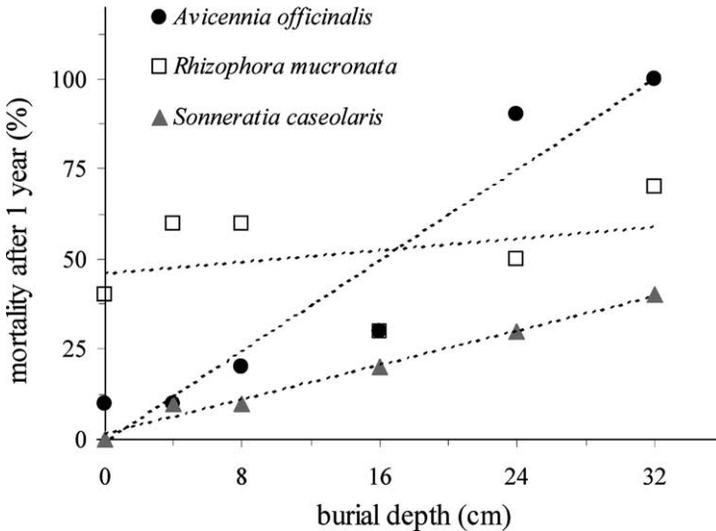


Fig. 2. Seedling mortality (%) at the end of the experiment as a function of burial depth. Linear regression fits were significant for *Avicennia* and *Sonneratia*: (respectively, $y = -0.88 + 3.16x$, $r^2 = 0.90$, $P < 0.05$; $y = 1.75 + 1.18x$, $r^2 = 0.98$, $P < 0.001$) but not for *Rhizophora* ($r^2 = 0.11$, $P > 0.05$).

The loss of seedlings during the experiment was modelled using the following non-linear equations:

- *Avicennia*:

$$\text{survivors} = 10.430 + 0.000(\pm 0.002) \text{ time} - 0.001(\pm 0.0001) \text{ burial} \times \text{time}$$

$$(r^2 = 0.87, P < 0.0001)$$

- *Rhizophora*:

$$\text{survivors} = 10.207 - 0.015(\pm 0.002) \text{ time} - 0.0001(\pm 0.0001) \text{ burial} \times \text{time}$$

$$(r^2 = 0.78, P < 0.0001)$$

- *Sonneratia*:

$$\text{survivors} = 10.004 - 0.001(\pm 0.001) \text{ time} - 0.0002(\pm 0.0001) \text{ burial} \times \text{time}$$

$$(r^2 = 0.51, P < 0.0001)$$

These regressions indicate that the factor time was a negligible source of seedling loss for *Avicennia* ($b_1 = 0$, $P = 0.998$: regression ANOVA tables not shown) and *Sonneratia* ($b_1 = 0$, $P = 0.270$) but was a highly significant source of seedling loss for *Rhizophora* ($b_1 \neq 0$, $P = 0.000$). In contrast, burial significantly increased the loss of seedlings in *Avicennia* ($b_2 \neq 0$, $P = 0.000$) and *Sonneratia* ($b_2 \neq 0$, $P = 0.002$). The number of surviving seedlings of these two species decreased at a rate of 0.001 and 0.0002 seedlings per day per centimeter of sediment burial, respectively. The absence of a burial effect in *Rhizophora* (Table 1) was confirmed by the multiple regression: the burial \times time factor was not significant ($b_2 = 0$, $P = 0.128$). *Rhizophora* seedlings died naturally at a rate of 0.015 seedlings per day (1 dead seedling in 67 days).

Temporal differences in seedling growth were significant, both in terms of internode production and height increase, and especially for *Avicennia* and *Sonneratia* ($P < 0.001$; Tables 2 and 3). The burial had a significant effect on the seedling relative growth rate (RGR_H) in *Avicennia* ($P = 0.008$) and *Sonneratia* ($P = 0.026$) but not in *Rhizophora* ($P = 0.986$; Table 2). The RGR_H of *Avicennia* was highest in the control seedlings

Table 2

Result of ANOVA with repeated measures^a examining the effects of sediment burial on height increase (RGR_H)

Factors	<i>Avicennia</i>			<i>Rhizophora</i>			<i>Sonneratia</i>		
	d.f.	SS	<i>P</i>	d.f.	SS	<i>P</i>	d.f.	SS	<i>P</i>
Treatment	4	3.50	0.008	5	0.03	0.986	5	2.44	0.027
Block	4	3.23	0.011	4	0.04	0.931	4	1.87	0.039
Treatment \times block	11	15.79	0.000	13	0.26	0.899	20	2.29	0.722
Within + residual	14	2.33		6	0.27		19	2.84	

^a The repeated measures factor (time) was significant in all the three species (tests of within subject contrast, $P < 0.001$ for *A. officinalis* and *S. caseolaris*, $P < 0.05$ for *R. mucronata*).

Presented are the degrees of freedom (d.f.), sums of squares (SS) and level of significance (*P*).

Table 3
Result of ANOVA with repeated measures^a examining the effects of sediment burial on internode production

Factors	<i>Avicennia</i>			<i>Rhizophora</i>			<i>Sonneratia</i>		
	d.f.	SS	P	d.f.	SS	P	d.f.	SS	P
Treatment	4	0.90	0.616	5	0.13	0.916	5	0.36	0.889
Block	4	1.73	0.316	4	0.20	0.730	4	0.74	0.523
Treatment × block	11	2.89	0.645	13	0.14	0.999	20	4.02	0.591
Within + residual	14	4.64		6	0.58		19	4.24	

^a The repeated measures factor (time) was significant in all the three species (tests of within subject contrast, $P \leq 0.001$). Also, the interaction of treatment and time was significant for *Avicennia* and *Sonneratia*. Twoway ANOVA (not shown) confirmed that treatment was only significant in the first two periods. Presented are the degrees of freedom (d.f.), sums of squares (SS) and level of significance (P).

($1.15 \pm 0.15 \text{ mm cm}^{-1}$ per month; Fig. 3) and declined gradually with increasing sediment levels. The seedlings of this species buried with the highest sediment depth (32 cm) had the lowest growth rate ($0.30 \pm 0.19 \text{ mm cm}^{-1}$ per month) and eventually died. In *Rhizophora*, the seedling RGR_H did not vary substantially amongst sediment levels and the seedlings receiving 4 cm of sediment had the highest RGR_H ($0.22 \pm 0.01 \text{ mm cm}^{-1}$ per month; Fig. 3) while the lowest RGR_H was observed in the 32 cm treatment. *Sonneratia* showed a higher growth rate than the other two species as well as had the lowest RGR_H at the deepest burial. Burial seemed to affect the internode production in the first stage of the experiment only.

A significant burial effect on overall internode production, was not detected in the repeated measures ANOVA for any of the three species studied (Table 3). When averaged over blocks and months, however, linear regressions suggest a decrease in internode production with burial for *Avicennia* and an increase for *Sonneratia* (Fig. 3). In addition, the *Sonneratia* seedlings produced a higher number of internodes (between 3.26 ± 0.37 and 3.68 ± 0.46 internodes per month; Fig. 3) than those of *Avicennia* and *Rhizophora*, a pattern similar to that observed for RGR_H .

4. Discussion

The three mangrove species tested in this experiment were found to differ substantially in their sensitivity to sediment burial. *Avicennia* survival decreased non-linearly with the level of burial resulting in severe mortality of the seedlings when buried with 32 cm of sediment. *Sonneratia* seedlings showed a similar pattern but the burial effect was smaller. In contrast, *Rhizophora* seedlings were not significantly affected by the burial levels and the seedling loss should be attributed to other factors not accounted for in this study. Possibly important factors are dry season high temperature and salinity stress (Hutchings and Saenger, 1987; McKee, 1995), wave dislodgment (Thampanya et al., 2002) and herbivory (Hutchings and Saenger, 1987; McKee, 1995; Farnsworth and Ellison, 1997). The increase in sensitivity to burial above 16 cm of the *Avicennia* seedlings is in agreement with the

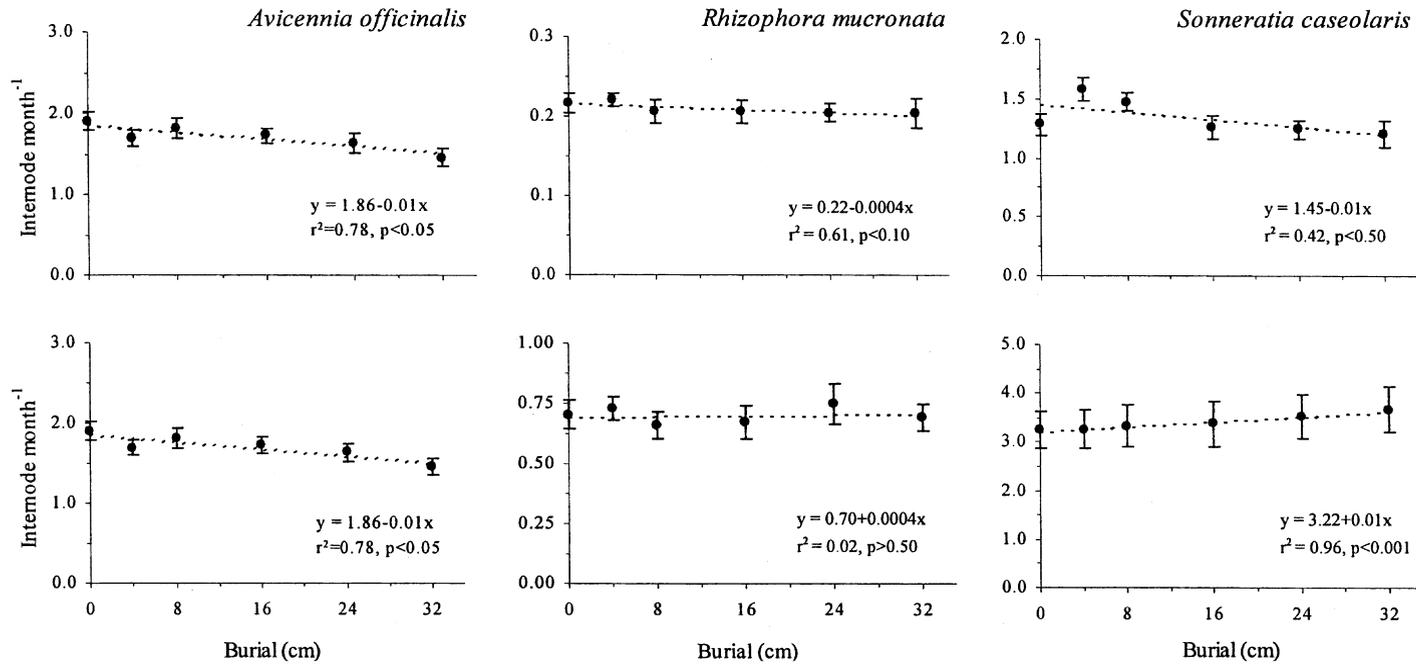


Fig. 3. Average relative height increase (RGR_H) and number of internodes produced over the experimental course versus burial depth. Overall repeated measures ANOVA results are presented in Table 3.

observation in Ellison's review (1999) suggesting that burial beyond 10 cm can cause mortality. The seedlings of *Sonneratia* in particular, survived remarkably well, grew faster than the seedlings of the other species and produced the highest number of internodes. Additionally, in our experiment, we observed the first pneumatophores in this species already after 6 months and these extended outside the experimental burial cylinder whilst the first pneumatophores in *Avicennia* reportedly are observed in the second year only (Ashford and Allaway, 1995; Skelton and Allaway, 1996). The development of pneumatophores as well as the rapid elongation of the stem may explain why *Sonneratia* coped so well with the burial.

Contrary to the finding of Terrados et al. (1997) for *R. apiculata*, sediment burial was found to have no significant effect for the closely related *R. mucronata* here. This may be due to a larger size of the propagule of the latter species (50–70 cm versus 20–30 cm for that of *R. apiculata*; Tomlinson, 1986). The remaining non-buried part of the seedling probably contains a number of lenticels (Youssef and Saenger, 1996) allowing a better aeration for *R. mucronata* and, hence, lower sensitivity to burial. Additionally, the finer sediment used by Terrados et al. (1997) in Pak Phanang (40% clay content versus 25% in Songkhla; Thampanya pers. data) may have been responsible for a more adverse rooting environment causing seedling mortality. This contrast justifies the comparative inclusion of several species in the present experiment.

Similar to survival, seedling growth was affected differently by sediment burial in the three tested species, whereas, the temporal differences (as repeated-measures) were always significant. Height increase of *Sonneratia* was the highest and burial had no significant effect on the growth of *Rhizophora*. The linear regressions of the overall internode production for *Avicennia* and *Sonneratia* were significant although the slopes were not steep. This was possibly due to a significant difference in internode production in the early part of the experiment. The repeated measures ANOVA, however, failed to detect significant differences in internode production affected by sediment burial in any species. Overall, this supports the findings of Duke and Pinzon (1992) and Duarte et al. (1998) that the annual number of internodes produced by a mangrove apex is a conservative and species-specific trait. Internodal lengths, however, vary seasonally as in e.g. seagrasses (Duarte et al., 1994) and may be highly sensitive to environmental changes (e.g. burial).

We have demonstrated in this study that sensitivity to burial varies substantially among species. Different taxa probably cope differently with the stress due to burial (reducing sediment conditions and less oxygen provided to root system). The size of a taller seedling of *R. mucronata* and the rapid development of pneumatophores in a faster growing *Sonneratia* appear to be useful strategies. Early colonizing species may encounter strong water currents as well as prolonged submergence, necessitating a rapid development of the root system and stem elongation as shown here for *Sonneratia*. In rehabilitation schemes, *Sonneratia* is probably an efficient colonizer for the areas with prolonged inundation or high sedimentation. *Avicennia* is also probably suitable in areas exposed to high water turbulence (Thampanya et al., 2002) as long as sediment deposit does not exceed 16 cm. *R. mucronata*, although not significantly affected by sediment burial, appears less suitable for plantation in areas with exposure to wind and waves. Field experiments prior to large-scale plantation schemes are advisable for reforestation programs using this economical important species.

Acknowledgements

The authors wish to thank Drs. Somsak Boromthananat and Carlos M. Duarte for useful advice. We also thank the Coastal Resources Institute, Prince of Songkla University for providing all research facilities and Chamnan Worachina, Phollawat Saijung for assistance in the field. This research is funded by the Netherlands Foundation for the Advancement of the Tropical Research (WOTRO Grant WB84-412).

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