Estuarine, Coastal and Shelf Science (1997) **45,** 697–701

The Effect of Increased Sediment Accretion on the Survival and Growth of *Rhizophora apiculata* Seedlings

J. Terrados[a], U. Thampanya[b], N. Srichai[b], P. Kheowvongsri[b], O. Geertz-Hansen[c], S. Boromthanarath[b], N. Panapitukkul[b] and C. M. Duarte[a]

[a]*Centro de Estudios Avanzados de Blanes, C.S.I.C., Camí de Santa Bárbara, s/n. 17300 Blanes (Girona), Spain*
[b]*Coastal Resources Institute, CORIN, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand*
[c]*Freshwater Biological Laboratory, University of Copenhagen, Helsingørsgade 51, DK 3400 Hillerød, Denmark*

Received 23 January 1997 and accepted in revised form 6 May 1997

The effects of experimental sediment accretion on the survival and growth of *Rhizophora apiculata* seedlings planted on an expanding mud flat in Pak Phanang Bay (south-east Thailand) were assessed. Seedling mortality rates increased linearly ($R^2=0{\cdot}87$, $F=75{\cdot}9$, $P<0{\cdot}0001$) with increasing sediment accretion, at a rate of 3% per cm of sediment deposited, and implied a 96% increase in mortality at the highest sediment accretion applied (32 cm). Similarly, seedling growth declined linearly with increasing sediment accretion ($r=-0{\cdot}95$, $P<0{\cdot}01$) with the seedlings receiving 32 cm of sediment showing no significant growth. These results clearly show that *Rhizophora apiculata* seedlings will not be efficient colonizers of coastal areas exposed to sudden events of high (>4 cm) sediment accretion and, therefore, afforestation programmes based on this species are unlikely to be successful in such areas. © 1997 Academic Press Limited

Keywords: mangrove seedlings; sediment accretion; *Rhizophora apiculata*; south-east Asia

Introduction

Deforestation, a widespread problem in south-east Asia (Panayotou, 1993), increases sediment delivery to the coastal zone, which in south-east Asia ranks amongst the highest on the planet (Milliman & Meade, 1983). Widespread deforestation leads to an increased frequency of flooding and sediment discharge during heavy rains, when as much as 10 cm of sediment may be deposited during a single event (Bamroongrugsa & Yuanlaie, 1995). In addition, aquaculture activities, which have boomed in the region, further increase the sediment inputs to the adjacent coast (Gujja & Finger-Stich, 1996). The increased sediment discharge to the coastal zone is expanding the mud flats in the area, thereby creating new habitat for mangrove colonization (Thom, 1984; Aksornkoae, 1993). As vegetative propagation is uncommon in mangroves (Tomlinson, 1994), the colonization of newly formed mud flats depends on the survival and growth of the established seedlings. Knowledge of the abiotic and biotic factors that control the mortality of mangrove seedlings is therefore essential to understand the development of mangrove forests (McKee, 1995), whether resulting from natural colonization or re-afforestation programmes. In particular, the establishment of mangroves over newly accreted mud flats may be limited by their ability to withstand sediment accretion, which may represent an obstacle to the success of natural and man-made mangrove colonization. However, the influence of increased sediment accretion on the survival and growth of mangrove seedlings remains to be investigated.

The aim of the present study was to examine the effects of experimental sediment accretion on the survival and growth of *Rhizophora apiculata* seedlings planted on an expanding mud flat in Thailand (Pak Phanang Bay, south-east Thailand). The authors focused on *R. apiculata* because it is one of the dominant species in south-east Asian mangrove forests (Tomlinson, 1994), and because it is widely used in afforestation programmes in this area (Aksornkoae, 1993). Mangrove trees are usually planted as young (<1 year) seedlings which may be quite sensitive to disturbance (McKee, 1993, 1995), such as that induced by an abrupt sediment discharge. The observed responses can be used to infer the likelihood of success of this species in habitats under contrasting sediment accretion, and help design successful afforestation programmes.

0272–7714/97/050697+05 $25.00/0/ec970262 © 1997 Academic Press Limited

Material and methods

The experiment was established in Pak Phanang Bay (8°25.11′N, 100°9.18′E), Nakhon Si Thammarat Province, southern Thailand. The eastern half of the bay is occupied by a 92·2 km^2 mangrove forest (*Avicennia marina*, *R. apiculata*, *R. mucronata*, *Bruguiera cylindrica*, *Excoecaria agallocha*) and an extensive mud flat. Tides are mixed with a range between 0·7 and 1·1 m for neap tide and spring tide, respectively (Flos, 1993). The Pak Phanang River, the main source of freshwater and sediments in the bay, discharge 15 $m^3 s^{-1}$ during the dry season, 30 $m^3 s^{-1}$ during the rainy season, and 120 $m^3 s^{-1}$ during the monsoon period, delivering 2×10^5 tons of sediment $year^{-1}$ to the Bay (Flos, 1993). The mangrove forest is extending on the eastern coast of the bay over a newly accreted mud flat.

Rhizophora apiculata seedlings of uniform age and vegetative development were obtained from the nursery of the Pak Phanang Mangrove Seedlings Center and planted on 1 June 1995 with a 2 m separation among them. The experiment followed a randomized block design with four blocks and three replicates of each experimental accretion level per block. Six sediment accretion levels were tested: 0—background accretion rate—, 2, 4, 8, 16 and 32 cm of sediment over the initial sediment level. In each block, the seedlings were spatially arranged in three parallel rows of six plants each and the sediment accretion levels were assigned randomly to each seedling. The increased sediment accretion was simulated by enclosing each seedling inside a PVC cylinder of 30 cm in diameter and different heights (10, 12, 14, 18 26 and 42 cm) according to the planned treatments, and filling the cylinder with mud collected at the same site. All cylinders were inserted 10 cm below the surface of the mud flat, and were stabilized using two 1 m poles attached in opposite points of the PVC cylinder. The sediment level inside the PVC cylinders was checked after 108 and 135 days and more sediment was added to maintain the experimental accretion levels if necessary.

The effect of the increased sediment accretion levels on the survival of the *R. apiculata* seedlings was assessed by counting the number of seedlings that remained alive after 108, 135 and 321 days. Seedling mortality and the effect of sediment accretion were examined using multiple regression analysis of the number of surviving seedlings against time (days) and accretion (cm), as described by the equation:

$$\text{Survivors} = a + b_1\text{time} + b_2\text{time}\cdot\text{accretion}$$

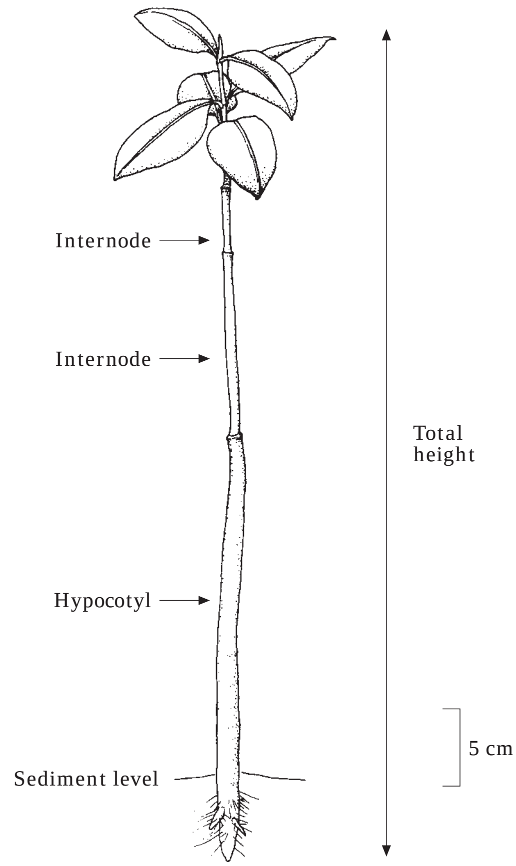

FIGURE 1. Schematic representation of the architecture of a *Rhizophora apiculata* seedling.

where b_1 provides an estimate of the daily loss rate of seedlings from control plots, and b_2 provides an estimate of the increase in the daily loss rate of seedlings per cm of sediment applied (i.e. the effect of sediment accretion on loss rate).

The effect of the experimental treatments on the growth of the seedlings was assessed by measuring their total height (cm) and counting the number of internodes on their main axis (Figure 1) at the onset of the experiment and after 108, 135 and 321 days. Seedling growth rate was estimated using least-squares linear regression analysis between the height of the seedlings or the number of internodes in each treatment and the time since the start of the experiment. At the last measurement date (15 April 1996), the number of branches of the main axis, the total length of the branches (cm), the length and width of 3 or 4 haphazardly selected leaves, and the number of leaves and roots were measured in each of the seedlings, and differences between experimental treatments were tested using the non-parametric Kruskal–Wallis ANOVA (Sokal & Rohlf, 1981).

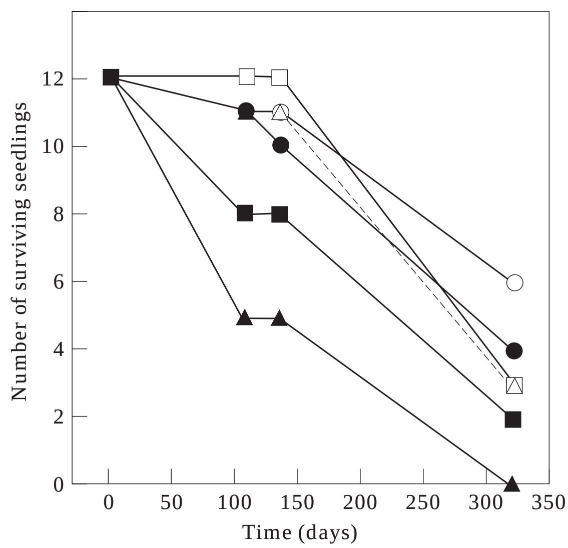

FIGURE 2. The change in the number of surviving *Rhizophora apiculata* seedlings throughout the experiment in relation to the initial sediment accretion imposed on the plants. ○, background; □, 2 cm; △, 4 cm; ●, 8 cm; ■, 16 cm; ▲, 32 cm.

Results

The number of surviving seedlings declined steadily throughout the experiment, both in control and treatment plants (Figure 2). Substantial mortality (33 to 58%) was already evident after 3·5 months in the plants that received 16 or 32 cm of sediment, whereas mortality of control plants and those receiving low sediment accretion was concentrated on the second half of the experiment (Figure 2). Seedling mortality within the first half of the experiment was high only on plants receiving high (>8) sediment accretions, but the loss experienced over the second part of the experiment was numerically similar across treatments. The widespread mortality during the second half of the experiment may be attributable to severe storms and sustained freshwater discharge in November and December 1995. Dead seedlings were still standing by the end of the experiment, but had no green leaves.

The changes in the number of surviving seedlings along the experiment were best described by the regression equation:

$$\text{Survivors} = 13{\cdot}5 - 0{\cdot}025\ (\pm 0{\cdot}003,\ \text{SE})\ \text{time} - 0{\cdot}00074\ (\pm 0{\cdot}0001;\ \text{SE})\ \text{time}\bullet\text{accretion}$$

$$R^2 = 0{\cdot}87,\ F = 75{\cdot}9,\ P < 0{\cdot}0001$$

These results indicate a loss of 0·025 control seedlings per day (1 dead seedling every 40 days), and a significant effect of sediment accretion on the mortality rate. The effect of sediment accretion significantly increased seedling mortality rates by 3% per each cm of sediment added, implying a 96% increase in mortality at the highest sediment accretion applied (32 cm).

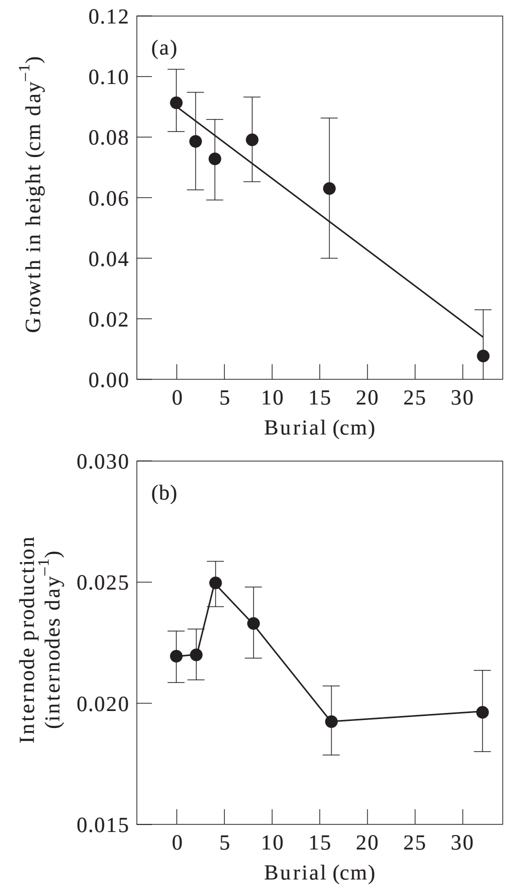

FIGURE 3. The relationship between the average (±SE) linear growth rate (a) and internodal production (b) of *Rhizophora apiculata* seedlings and the initial sediment accretion imposed on the plants. Solid line in (a) represents the fitted linear regression equation.

Seedling growth rates averaged $0{\cdot}091 \pm 0{\cdot}010$ (mean ± SE) cm day^{-1} in control plots, and were also significantly influenced by the treatment level applied [Figure 3(a)]. Growth rates declined steadily from controls to plants that received 16 cm of sediment (growth rate $0{\cdot}067 \pm 0{\cdot}014$ cm day^{-1}), with the plants receiving 32 cm of sediment showing no significant growth (growth rate $0{\cdot}007 \pm 0{\cdot}015$, $P > 0{\cdot}05$). Accordingly, there was a strong ($r = -0{\cdot}95$), significant ($P < 0{\cdot}01$) negative correlation between seedling growth rate and sediment accretion. There was no significant change in the rate of production of internodes with sediment accretion, which showed a small range of variation among treatments from $0{\cdot}019 \pm 0{\cdot}001$ internodes day^{-1} to $0{\cdot}025 \pm 0{\cdot}001$ internodes day^{-1} in plants receiving 16 and 4 cm of sediments, respectively [Figure 3(b)]. No significant differences (Kruskal–Wallis, $P>0{\cdot}05$) were found in the number of branches, roots, leaves or leaf surface of the seedlings with the different sediment accretion rates at the end of the experiment.

Discussion

These results clearly demonstrate that sediment accretion increases the mortality rate of *R. apiculata* seedlings. The mechanisms by which this occurs cannot be elucidated here. They are, however, unlikely to involve factors related to the development of the root system or photosynthetic surface, since these did not differ between control and treatment plants. A possible factor may be an altered oxygen supply to the hypocotyl and root system of *Rhizophora* seedlings due to sediment accretion. In particular, sediment accretion may interfere with the role of lenticels in the aeration of the below ground root systems (Tomlinson, 1994). The only source of oxygen to belowground organs when the hypocotyl lenticels are covered by sediment would be the translocation of that produced by the leaves, which is likely to be slow because the lacunar pathway is supposed to have one of the highest diffusional resistances in the stem-hypocotyl junctions (Youssef & Saenger, 1996). Whatever the factors responsible for the negative effect of sediment accretion on seedling survival, these must also influence the carbon balance of the plants, since linear plant growth rates declined with increasing sediment accretion. On the other hand, a reduced supply of oxygen to belowground organs might decrease the tolerance to the phytotoxins present in anaerobic sediments (McKee, 1993; Youssef & Saenger, 1996).

The increase in mortality rate occurred largely during the first few months following sediment accretion, indicating that sudden sediment deposition events, such as those occurring during heavy floods, will lead to reduced growth or mortality, depending on the thickness of the sediment layer deposited, of mangrove seedlings after a delay of a few weeks. In contrast, the rate of internodal production showed only minor changes in response to sediment accretion. This observation reinforces the suggestion that seedling internode production is a conservative trait and supports the use of the number of internodes to establish the age of young mangrove plants (Duke & Pinzón, 1992). Similarly, the rate of branch and root production did not differ with increasing sediment accretion, suggesting these traits to be also part of the basic growth programme of the plants.

These results clearly show that *R. apiculata* seedlings will not be efficient colonizers of coastal areas exposed to sudden discharges of sediments, such as those with highly eroding watersheds. *Avicennia* spp. and *Sonneratia* spp. are known to be the prime colonizing species in newly formed mud flats in south-east Asia (Tomlinson, 1994; Lee *et al*., 1996), where *Rhizophora* spp. play a minor role in this process. The mechanisms that enable *Avicennia* spp. and *Sonneratia* spp. to colonize these areas are as yet unknown, but in the case of *Avicennia* spp. the adequate supply of oxygen to belowground organs resulting from the high porosity of the roots (Youssef & Saenger, 1996) might be involved. Afforestation programmes in south-east Asia predominantly use *Rhizophora* spp. as the target species. The reason for this choice is the economic value of the grown trees, and their associated availability from nurseries. These results, however, strongly suggest that afforestation programmes based on *R. apiculata* are unlikely to be successful to establish mangroves in areas with sudden events of high sediment accretion.

Acknowledgement

This research was funded by the contract TS3*-CT94-0301 of the STD-3 programme of the European Commission. The authors thank the Pak Phanang Mangrove Seedlings Center authorities for providing the seedlings used, Dr N. Bamroongrugsa for advice, A. Phaiboon, P. Billae, J. Kenworthy, J. Borum, L. Kamp-Nielsen, S. Bach and I. Wesseling for assistance in the field, and G. Carreras for the artwork.

References

Aksornkoae, S. 1993 *Ecology and Management of Mangroves*. IUCN, Bangkok.

Bamroongrugsa, N. & Yuanlaie, P. 1995 Mangrove Afforestation on newly formed mudflats of the Patani Bay, Southern Thailand. In *Ecology and Management of Mangrove Restoration and Regeneration in East and Southeast Asia. Proceedings of the ECOTONE IV, 18–22 January 1995, Surat Thani* (Khemnark, C., ed.). Kasetsart University, Bangkok, pp. 230–238.

Duke, N. C. & Pinzón, Z. S. 1992 Aging *Rhizophora* seedlings from leaf scar nodes: a technique for studying recruitment and growth in mangrove forests. *Biotropica* **24,** 173–186.

Flos, S. J. 1993 *Estimations of Freshwater Flow through the Pak Phanang River*, M.Sc. Thesis, University of Humberside, U.K.

Gujja, B. & Finger-Stich, A. 1996 What price prawn? Shrimp aquaculture's impact in Asia. *Environment* **38,** 12–39.

Lee, S. K., Tan, W. H. & Havanond, S. 1996 Regeneration and colonisation of mangrove on clay-filled reclaimed land in Singapore. *Hydrobiologia* **319,** 23–35.

McKee, K. L. 1993 Soil physicochemical patterns and mangrove species distribution—reciprocal effects? *Journal of Ecology* **81,** 477–487.

McKee, K. L. 1995 Seedling recruitment patterns in a Belizean mangrove forest: effects on establishment ability and physico-chemical factors. *Oecologia* **101,** 448–460.

Milliman, J. D. & Meade, R. H. 1983 World-wide delivery of river sediment to the oceans. *Journal of Geology* **91,** 1–21.

Panayotou, T. 1993 The environment in Southeast Asia: problems and policies. *Environmental Science and Technology* **27,** 2270–2274.

Sokal, R. R. & Rohlf, F. J. 1981 *Biometry*. W. H. Freeman, New York.

Thom, B. G. 1984 Coastal landforms and geomorphic processes. In *The Mangrove Ecosystem: Research Methods* (Snedaker, S. C. & Snedaker, J. G., eds). Unesco, Paris, pp. 3–17.

Tomlinson, P. B. 1994 *The Botany of Mangroves*. Cambridge University Press, Cambridge.

Youssef, T. & Saenger, P. 1996 Anatomical adaptive strategies to flooding and rhizosphere oxidation in mangrove seedlings. *Australian Journal of Botany* **44,** 297–313.

The author has requested enhancement of the downloaded file. All in-text references underlined in blue are linked to publications on ResearchGate.