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ORIGINAL ARTICLE

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Early growth of seven mangrove species planted at different elevations in a Thai estuary

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Abstract This study aimed to determine the effect of elevation on survival and growth of mangrove seedlings during the establishment period. Seven typical mangrove species, *Rhizophora mucronata* Poir, *R. apiculata* Bl., *Bruguiera cylindrica* (L.) Bl., *Ceriops tagal* (Pirr.) C.B. Rob., *Sonneratia alba* J. Sm., *Avicennia officinalis* L. and *Xylocarpus granatum* Koenig were planted at various topographic sites in an intertidal zone of Phang Nga province, southern Thailand. These six bare areas included two that were abandoned after tin mining and four gap areas in natural habitats in June 1998. The experimental plots were on a slope and showed a maximal elevation difference of 1.8 m. The plots were naturally submerged with 2–3% saline water twice a day. Salinity, pH and the concentrations of several ions in the soil water were similar in all the plots. Survival and growth performance of seedlings were measured every 6 months. Many seedlings of *B. cylindrica*, *C. tagal* and *X. granatum* planted at lower elevations died with a year. *R. mucronata* and *S. alba* survived even at the lowest elevations, but showed changes in growth rate in response to topography. Thus, early growth of the seven mangrove species at different elevations differed and showed increasing tolerance to higher tidal inundations in the order: *R. mucronata*, *S. alba*, *R. apiculata*, *A. officinalis*, *C. tagal*, *B. cylindrica* and *X. granatum*. These findings provide guideline information for appropriate species selection in a mangrove rehabilitation program.

Keywords Intertidal zone · Mangrove forest · Restoration · Survival · Topography

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Introduction

Development programs on mangrove rehabilitation are urgent issues in tropical and sub-tropical coastal regions. Until recently, only a few key species of mangrove trees have been used to restore the degraded woody parts of the coastal ecosystem. Interest in using further species is growing but knowledge necessary to guide rehabilitation efforts, especially with regard to species selection for specific areas, is very limited. More research on species selection and monitoring of survival and plant growth in different soil and water conditions is required for successful mangrove rehabilitation (Jintana and Piriyayotha 2000).

Komiyama et al. (1996) reported that microtopography affected the survival and growth of seedlings of *Rhizophora apiculata* BL. in an abandoned tin-mining area. Determining the effect of elevation on survival and growth of mangrove seedlings is important for successful plantation of mangroves in intertidal zones. However, there have been few comparative studies of this type using several mangrove species.

The objective of this present study was to reduce the information gap on species–site matching for mangrove restoration. Survival and growth characteristics of seven mangrove species were investigated under different topographic conditions. This gave an indication of the tolerance to tidal inundation and inundation period of these species.

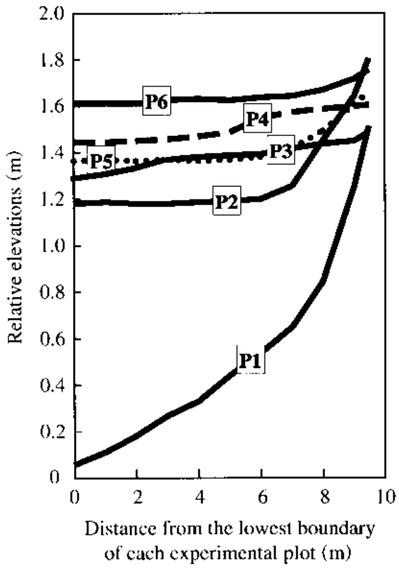


Fig. 1 Relative elevation in six experimental plots. Relative elevation is expressed as elevation differences from the lowest point in plot P1

Materials and methods

Six experimental plots were set up in bare areas of intertidal zones inside and outside a mangrove forest managed by Mangrove Seed Production Center 8°20′N and 98°25′E in Phang Nga province, southern Thailand. The plant materials used were viviparous seeds of *Rhizophora mucronata* Poir, *R. apiculata* Bl., *Bruguiera cylindrica* (L.) Bl. and *Ceriops tagal* (Pirr.) C.B. Rob., and 6-month-old seedlings of *Sonneratia alba* J. Sm., *Avicennia officinalis* L. and *Xylocarpus granatum* Koenig, all collected from natural habitats. These were introduced into six experimental plots in June 1998. The plots included four gap areas in natural habitats (P1, P2, P3, P4) and two abandoned tin-mining area (P5, P6) where tin mining ceased 15 years ago. Each plot had an area of 12×10 m^2. The experimental plots were sloping. P1 was the lowest plot (Fig. 1). The mean elevations of P2, P3, P4, P5 and P6 were 0.75, 0.82, 0.95, 0.87 and 1.08 m, respectively, higher than P1. The elevation difference between the lowest and highest points of all plots was 1.8 m. The plots were submerged with 2–3% saline water twice a day. The highest tidal level was 2.7 m from the soil surface at the lowest point in plot P1 in March.

Sixty plants of each species were planted with a spacing of 0.5 m in a matrix of 3×20 in each plot. Percentage survival and growth characteristics were checked 6 months and 1 year after planting. Percentage survival was calculated from the number of surviving trees divided by the total number of planted trees from the six experimental plots, averaged every 0.2 m of elevation regardless of which plot. Lengths of main stems of all species, diameters of main stems 20 cm below the top of hypocotyls of *R. mucronata*, *R. apiculata*, *B. cylindrica* and *C. tagal*, and 20 cm above the soil surface for *S. alba*, *A. officinalis* and *X. granatum* were measured. Increase in these parameters was used as an indicator of growth rate over 6 months and 1 year. The above-mentioned parameters of all trees from the six experimental plots were also averaged every 0.2 m of elevation regardless of the plots. The effects of elevation on these parameters were analyzed by ANOVA.

Salinity, pH and concentrations of the ions Fe^{2+}, K^{+}, PO_4^{3-}, Mn^{2+} and $Sn^{2+/4+}$ in the soil water were measured in June. Soil water was collected with soil water samplers (DIK-301A, Daiki Rika Kogyo, Japan) using a syringe, a microtube and a porous suction opening at depths of 10, 30 and 60 cm from the soil surface at each corner of each plot. The salinity of sample water was measured with an optical salinity meter (S-100, Atago, Japan). The pH and ion concentrations were determined with test papers (Merckquant, Merck) and a colorimeter (NR-3000, Nippon Densyoku, Japan). Air temperature and relative humidity were measured at 1.5 m height at each plot in March and July.

Results

The pH values in the soil water were very similar in plots P1, P2, P3 and P4, with a mean value of 7.0 (Table 1). In plots P5 and P6 in the abandoned tin-mining area, the mean pH value was 6.7, showing the existence of low pH near the soil surface. Salinity in the soil water tended to be lower at more shallow depths (Table 1). The salinity readings were very similar in all the plots at the same depths. The concentrations of Fe^{2+}, K^{+} and PO_4^{3-} in the soil water were almost the same in all the plots (Table 1). The concentrations of $Mn^{2+}$and $Sn^{2+/4+}$ in the soil water were lower than the detection limit with the present method (2 mg l^{-1} and 10 mg l^{-1}, respectively). The hardness of the soil showed no notable differences between the plots.

Air temperature and relative humidity were measured for 3 days in March and July and were almost the same in plots P1, P2, P3 and P4. The maximal air temperature was 2°C higher and the minimal relative humidity 5% lower in P5 and P6 than in the other plots during the daytime (Fig. 2).

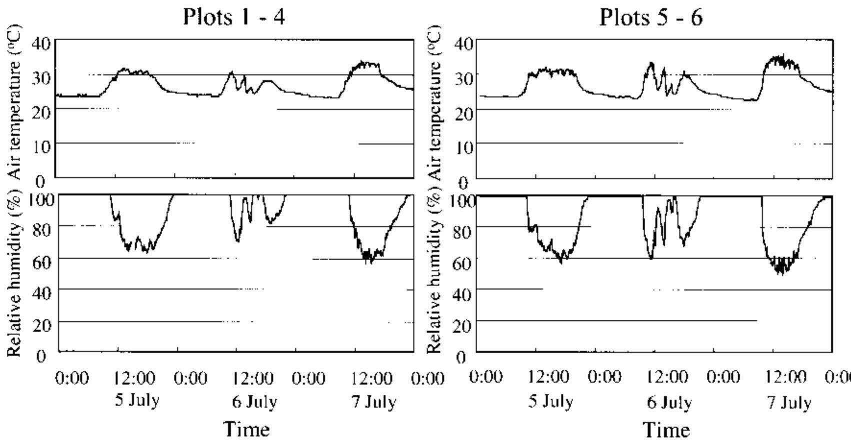
There were no significant differences in soil properties and atmospheric conditions between the plots that would be expected to influence growth. Therefore, we conclude that the variation in survival and growth characteristics was mainly dependent on elevation and thus on tidal inundation periods.

Percentage survival of the seven mangrove species as affected by elevation is shown in Fig. 3. All species showed lower survival at lower elevation. *R. mucronata* survived in all the plots regardless of elevation for 1 year

Table 1 Mean ±SD of pH, salinity, and the concentrations of Fe^{2+}, K^{+} and PO_4^{3-} in the soil water at three depths in plots P1, P2, P3 and P4 and plots P5 and P6

Plot	Depth (cm)	pH	Salinity (%)	Fe^{2+} (mg l^{-1})	K^{+} (mg l^{-1})	PO_4^{3-} (mg l^{-1})
1–4	10	6.9±0.5	2.0±0.3	7.8±3.1	551±15	99±27
	30	7.0±0.3	2.4±0.4	7.5±5.6	548±20	89±19
	60	7.0±0.3	2.4±0.4	10.0±7.8	550±19	126±72
5–6	10	6.3±1.0	2.3±0.4	10.0±5.5	538±32	107±18
	30	6.8±0.6	2.4±0.4	11.6±6.9	543±17	111±13
	60	7.1±0.2	2.7±0.4	7.2±1.5	539±20	121±70

Fig. 2 Air temperature and relative humidity during 3 days in July 1999. Mean values are shown for plots P1, P2, P3 and P4 and plots P5 and P6



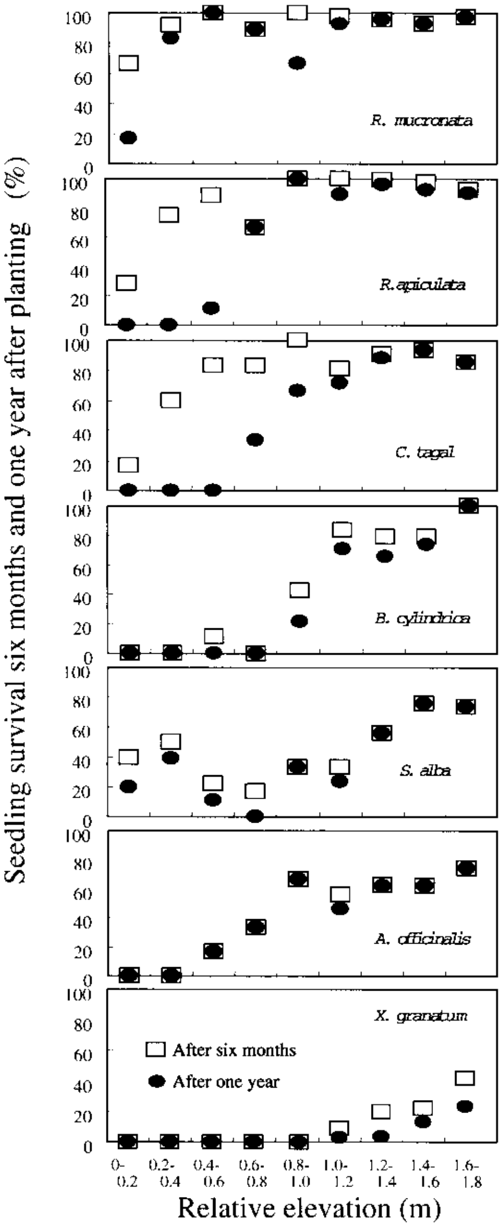


Fig. 3 Percentage survival after 6 months and 1 year of seven mangrove species planted at different elevation ranges

after planting. Eighty percent of *R. mucronata* were still alive at an elevation of 0.2–0.4 m. *S. alba* also survived at the lowest elevation range of 0–0.2 m. *R. apiculata* and *A. officinalis* survived at elevations higher than 0.4 m. Plants of *X. granatum* mostly died at elevations less than 1.4 m. Most plants of *R. mucronata*, *R. apiculata* and *C. tagal* survived at elevations higher than 1.0 m. Only 20% of plants of *X. granatum* survived at even the highest elevation range of 1.6–1.8 m. Many plants of *R. apiculata* and *C. tagal* survived at elevations lower than 0.6 m after 6 months but had mostly died after 1 year.

Elevation significantly affected increments in length and diameter of main stems of all mangrove species ($P<0.05$). The interaction of elevation and species was also significant at $P<0.05$.

Stem elongation of the seven mangrove species as affected by elevation is shown in Fig. 4. All species showed different stem elongation rates in response to topography. The mean stem elongation rate of plants that survived for 1 year was highest in *R. mucronata* followed by *R. apiculata*, *A. officinalis*, *S. alba*, *C. tagal* = *B. cylindrica* and *X. granatum*. *R. mucronata* showed a tendency towards higher stem elongation at elevations of 0.2–0.8 m compared with other elevations. The stem elongation of *R. apiculata* decreased with increasing elevation from 0.4 to 1.8 m. *S. alba* and *A. officinalis* showed higher stem elongation at higher elevations, the reverse of the tendency with *R. mucronata* and *R. apiculata*. The stem elongation rates of *C. tagal*, *B. cylindrica*, *S. alba* and *A. officinalis* were higher in the second than in the first half-year, while *R. mucronata*, *R. apiculata* and *X. granatum* in general showed the reverse tendency.

Increase in stem diameter of the seven mangrove species as affected by elevation is shown in Fig. 5. *R. mucronata*, *C. tagal*, *S. alba* and *A. officinalis* showed different rates of stem diameter increase in response to topography, while *R. apiculata* and *B. cylindrica* showed a constant stem expansion rate regardless of elevation. *R. mucronata* had the thickest stems at elevations of 1.0–1.2 m and thin stems at lower elevations of 0–1.0 m. The stem diameters of *C. tagal*, *S. alba* and *A. officinalis* tended to increase with increasing elevation, while *X. granatum* showed the reverse tendency.

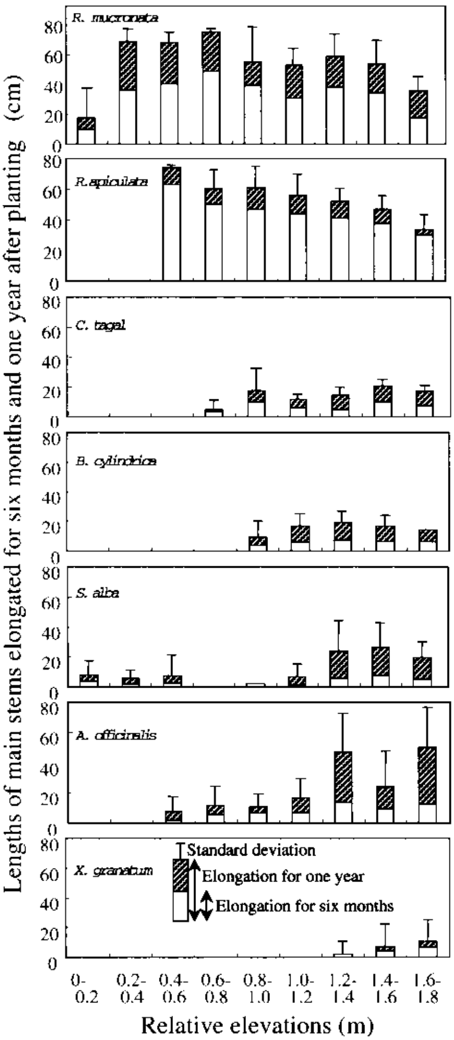


Fig. 4 Stem elongation of seven mangrove species planted at different elevation ranges after 6 months and 1 year. Measurements are for plants that survived for a full year. Values are mean + SD

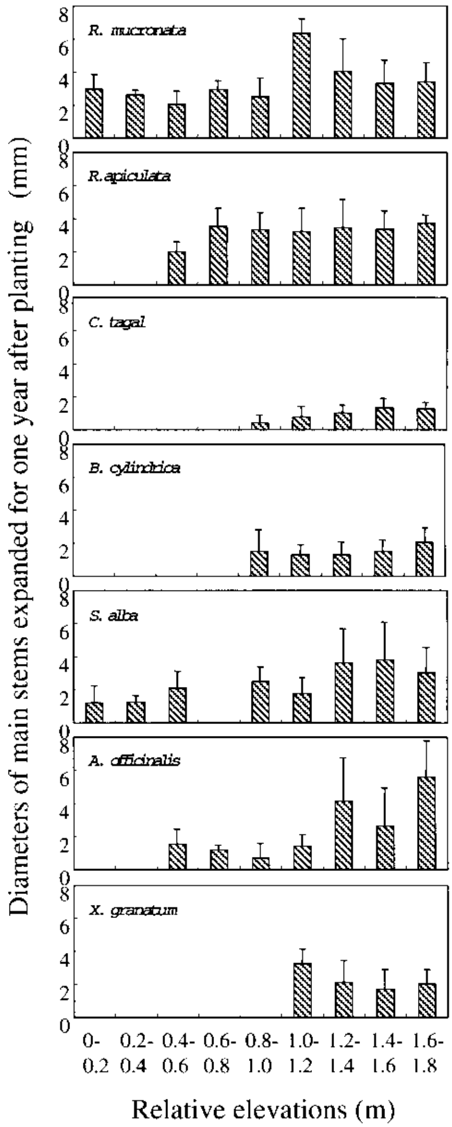


Fig. 5 Expansion of stem diameters after 6 months and 1 year of seven mangrove species planted at different elevation ranges. Measurements are for plants that survived for a full year. Values are mean + SD

Discussion

Possible effects of tidal inundation on seedling growth of mangroves have been suggested for *R. apiculata* and *B. gymnorriza* (Sukardjo 1987) and for *R. mangle*, *A. germinans* and *Laguncularia racemosa* (McKee 1995). Seedlings of *A. marina*, *B. gymnorriza*, *C. tagal* and *R. stylosa* were reported to show lower survival at lower intertidal elevations (Smith 1987). The results of our experiment in which plants were grown under different inundation regimes in field conditions without confounding variations in salinity and other chemical properties of soil water confirm these previous reports. The intertidal elevation affects tidal inundation and the inundation period. Mangroves showing higher survival at low elevation are considered to have tolerance to a high tidal inundation and longer inundation periods. Inundation for prolonged periods resulted in lower stomatal conductance in *B. gymnorrhiza* (Naidoo 1983) and *R. stylosa* (Kitaya et al., unpublished data) and in lower net assimilation rate in *R. mangle* (Ellison and Farnsworth 1996). Mangroves showing higher percentage survival at low elevation in the present experiment would maintain higher stomatal conductance after inundation for prolonged periods. Survival and growth of mangrove seedlings were affected by even a slight elevation difference of 0.2 m. Komiyama et al. (1996) also reported that microtopography affected survival and growth of seedlings of *R. apiculata* BL. in an elevation range of just 0.35 m.

We may conclude that mangrove plants have increasing tolerance to inundation in the order *R. mucronata*, *S. alba*, *R. apiculata*, *A. officinalis*, *C. tagal*, *B. cylindrica* and *X. granatum* at an early growth stage. We expect that our findings will provide guideline information for appropriate species selection in a mangrove rehabilitation program.

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