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Distribution of fine-root necromass in a secondary mangrove forest in Trat province, Eastern Thailand

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ABSTRACT: The aim of this study was to determine the amount of fine-root necromass among the three different principal vegetation zones (*Avicennia-Sonneratia*, *Rhizophora*, and *Xylocarpus*) in a secondary mangrove forest in eastern Thailand. The coring method was applied for the estimation of the fine-root necromass. The results revealed a high proportion of fine- to total root-necromass (66.3%, 50.2% and 67.5% in the *Avicennia-Sonneratia*, *Rhizophora*, and *Xylocarpus* zones, respectively), and a very high proportion of dead to total fine root mass (91.8%, 96.6%, and 98.5%, respectively). A statistically insignificant but numerical difference was found in the vertical distribution of the fine-root necromass in the three soil depths examined (0–10, 10–20, and 20–30 cm deep from the surface) in all three zones. However, the zonal distribution of the fine-root necromass was significantly different among the zones and accumulated in the order of the *Xylocarpus* > *Rhizophora* > *Avicennia-Sonneratia* zones with an average of 9.94 ± 2.49, 21.1 ± 2.7, and 90.0 ± 14.3 t $ha^{-1}30\ cm^{-1}$, respectively. These are discussed in relation to the CO_2 efflux via soil respiration formerly measured in the same study site. The ratio between dead and live fine-root mass showed a tendency to increase with increasing distance from the river edge, and this may relate to the rising elevation from the mangrove forest towards a more terrestrial habitat.

KEYWORDS: fine-root mass, mangrove zonation

INTRODUCTION

Mangrove forests are highly productive ecosystems with a large net primary productivity (NPP), being reflected by huge biomasses [1–3]. However, some studies have shown that a large amount of the mangrove biomass is in the below ground level root system [4–6].

Fine roots (diameter < 2 mm) are the primary pathway for water and nutrient uptake by plants and play an important role in the carbon dynamics of forest soils [7]. They appear to be extremely important in terms of the ecosystem NPP [8] because of their short life span and high turnover rate [9]. If the dead fine roots are not decomposed, they will accumulate as root necromass in forest soils, trapping carbon in the forest ecosystem. Supporting the notion of an accumulation of fine-root necromass in mangrove forests, some studies have indicated that mangrove forests emit a lower CO_2 level from soil respiration than terrestrial forests [10–12]. Nevertheless, few studies have examined the actual amount of fine-root necromass [13].

The change in dominant tree species in mangrove forests is influenced by the distance from the river due to a resultant gradient of related environmental factors [14]. The present study compares the fine-root necromass among the three principal vegetation zones in a secondary mangrove forest. We hypothesized that the amount of fine-root necromass is different among the vegetation zones.

MATERIALS AND METHODS

Study location

The study site is located in a secondary mangrove forest on an estuary of the Trat River, Trat province, eastern Thailand (12°12'N, 102°33'E). In the past, this forest was exploited for timber and charcoal production. However, since the 1980's, the Mangrove Forest Learning and Development Centre No. 1 (Department of Marine and Coastal Resources, Thailand) have managed this as a regeneration forest. The mean annual temperature and precipitation in this area from 1997–2008 were 26.5–29.8 °C and 5000 ± 875 mm (Department of Meteorology, Thailand), respectively, with a relative humidity of ~80%. The area of mangrove forest on this estuary is mostly affected by a single tide (Royal Thai Navy, Thailand).

A permanent plot of 50 m × 120 m in size (Fig. 1) was established. Tree diameters (dbh) for trees with a diameter of more than 4.5 cm were measured and identified. Tree density (> 4.5 cm dbh) was 1877 stems/ha, and the average stem diameter (dbh) was

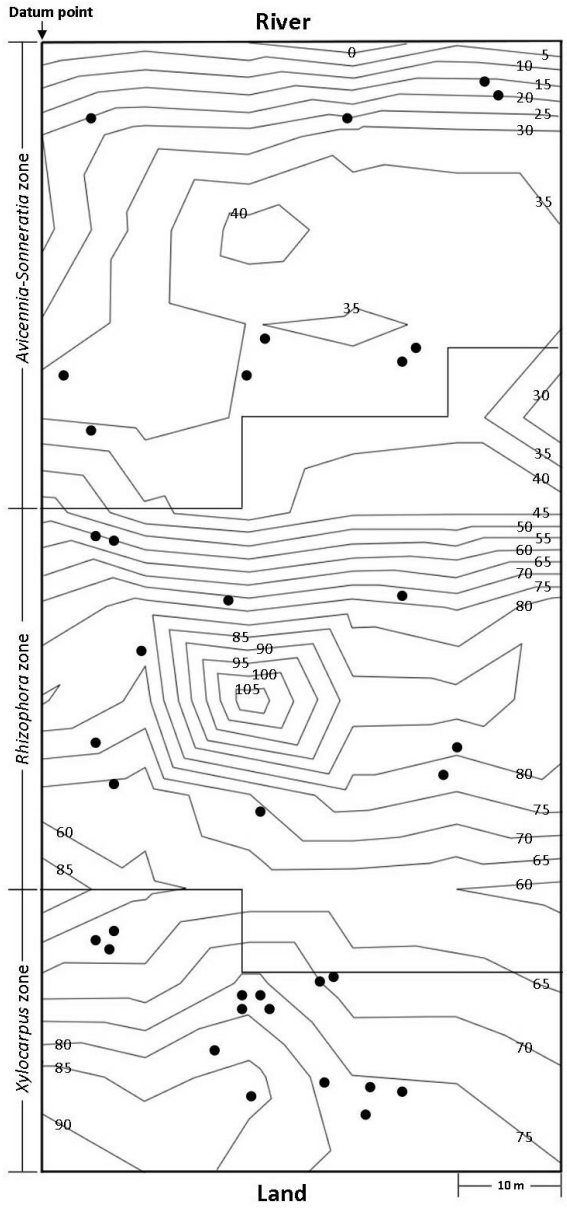

Fig. 1 The permanent experimental plot (50 m × 120 m), showing the contour lines of elevation and vegetation zones (*Sonneratia-Avicennia*, *Rhizophora*, and *Xylocarpus* zones). Solid circles represented the places where the 30 cm vertical core samples were randomly taken in each zone for the evaluation of the fine-root necromass.

11.3 cm, with a total basal area of 0.66 m^2/ha. The forest biomass and litter production were estimated at 291.4 t/ha and 10.15 t ha^{-1} yr^{-1}, respectively, in 2009 (Poungparn, unpublished).

The study site was clearly divided into three vegetation zones based on the dominant tree species. The first zone was at the edge of the river and was occupied by *Sonneratia caseolaris* and *Avicennia alba* as the dominant species and so formed the so called *Avicennia-Sonneratia* zone. The average elevation was the lowest in this zone (Fig. 1), and so the inundation period was the longest. Pneumatophores were densely distributed on the forest floor. The soil was soft mud with a level of underground water at the soil surface during low tide. In the second zone, next to the inland part of this zone, the forest was dominated by *Rhizophora mucronata* and *Rhizophora apiculata* which produced many stilt roots on soft mud. The average level of underground water during a low tide was 3.5 cm. The third zone mostly contained *Xylocarpus granatum*, *Bruguiera gymnorrhiza*, and *Ceriops tagal* with root buttresses. However, *Xylocarpus granatum* was dominant, and so this was called the *Xylocarpus* zone. The soil of this zone was sandy clay, and had a relatively low level of underground water (6.1 cm). Located on the most inland part of the study plot, the *Xylocarpus* zone had the shortest period of inundation among the three zones.

Measurement of soil temperature

Temperature sensors and data loggers (TidbiT v2 Temperature data logger, Onset Computer Corporation) were installed into each zone at a depth of 10 cm. One set was installed to measure the water temperature in the river at the front of the study site. The data loggers were set to record temperature every 30 min from August 2008 to August 2009.

Estimation of fine-root necromass

The coring method [15] was applied for estimation of the fine-root necromass. A core was made by vertically inserting a PVC pipe (30 cm in length and 8 cm in diameter) into the soil until the top end of the core was at the soil surface. The removed soil column was then divided into three parts, namely, 0–10 cm, 10–20 cm, and 20–30 cm depth. Ten soil cores were randomly collected in the *Avicennia-Sonneratia* and *Rhizophora* zones, and 15 cores were taken from the *Xylocarpus* zone. Each soil core was put in a stainless steel sieve with a mesh size of 250 μm (Endecotts Ltd., UK), and washed with tap water. The separated residues on the sieve were soaked in water to distinguish living from dead roots, based upon their colour and firmness [16]. Living roots were classified as turgid and white in colour. The dead roots or root necromass were sorted into two categories according to their diameter: (i) fine roots ($\leqslant$ 2 mm) and (ii) non-fine roots ($>$ 2 mm). The dry weight of all roots was obtained after they had been oven dried at 85 °C to a constant weight.

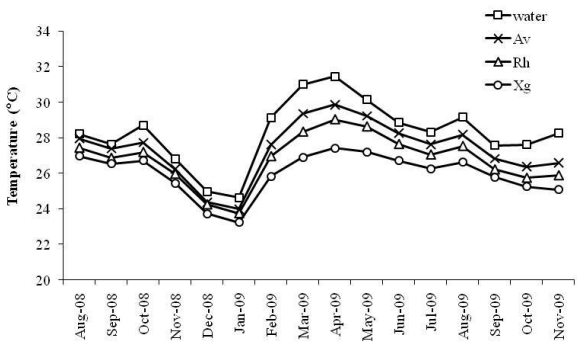

Fig. 2 Monthly soil temperature among the three vegetation zones and river water temperature during August 2008 – August 2009. For the soils: Av=*Avicennia-Sonneratia* zone, Rh=*Rhizophora* zone and Xg=*Xylocarpus* zone; water=river water.

Statistical analysis

Statistical analysis was performed using SPSS (version 14.0) for Windows. The effects of zonation and soil depth on the amount of the fine-root necromass were tested by two-way ANOVA. The analysis of significant differences in the amount of fine-root necromass was tested by least significant difference.

RESULTS AND DISCUSSION

Soil temperature

The average water temperature during 1st August 2008 to 1st August 2009 was 28.4 °C with a high of 31.4 °C in April and a low of 24.3 °C in January (Fig. 2). The average soil temperature in the *Avicennia-Sonneratia*, *Rhizophora*, and *Xylocarpus* zones was 27.5, 27.0, and 26.1 °C, respectively, with the highest and lowest average monthly temperatures being recorded in April and January, respectively (Fig. 2). The water temperature was significantly different from the soil temperature in *Xylocarpus* zone (ANOVA, $F_{(4,60)} = 3.64$; $P < 0.01$) only, but a consistent trend of a slight numerical difference in the soil temperature among the three zones (*Avicennia-Sonneratia* > *Rhizophora* > *Xylocarpus*) was noted, although it was not statistically significant ($P > 0.05$).

Distribution of fine-root necromass within each zone

The total fine-root necromass among the three soil depths (0–10, 10–20, and 20–30 cm) was not significantly different between the three soil depths in each of the three zones (Table 1), with the average fine-root necromass being 3.31 ± 2.49, 7.02 ± 2.65 and 29.99 ± 14.28 t ha^{-1} 10 cm^{-1} in the *Avicennia-Sonneratia*, *Rhizophora*, and *Xylocarpus* zones, respectively. The abundant fine roots on the top 30 cm of the soil surface might be a physiological adaptation in mangrove forest species to facilitate the efficient uptake of water and nutrients which are usually abundant in this layer[17]. The trees in the *Avicennia*, *Sonneratia*, and *Xylocarpus* genera produce cable roots from the tree trunk. These roots then distribute horizontally along the soil surface and produce many pneumatophores vertically above the soil surface to enable gas exchange. The buried part of the pneumatophore generates many fine roots near to the soil surface[17].

Likewise, although most of the fine root mass was dead (91.6, 96.6, and 98.5% in the *Avicennia-Sonneratia*, *Rhizophora*, and *Xylocarpus* zones, respectively), the proportion of necromantic fine roots to the total (live plus dead fine roots) did not significantly vary between the three soil depths within each of the three zones. This reflects the lack of significant variation in the live fine root biomass between the three soil depths within each zone. Thus the vertical distribution of total root necromass among the three soil depths was comparable within each site. However, with respect to the total (fine and non-fine) dead root mass the *Rhizophora* zone showed an apparent lower amount in the 0–10 cm soil depth than the other two deeper samples. This is because of the low proportion of dead non-fine root material. This trend, however, was not observed in the other two zones.

The high proportion of fine-root necromass in this mangrove forest may well have arisen as a result of three interacting factors. The first is the high density of fine roots produced in the system. The second is the short life-span of the fine roots[9,18] which means that they would be expected to have a fast generation rate so as to maintain a high density of viable fine roots. Lastly, the fine roots decompose more slowly in mangrove forests (0.043–1.022 g/yr)[19,20] than in tropical terrestrial forests (0.60–1.27 g/yr)[21,22]. Thus the difference in the regeneration rate over the degradation rate, coupled with the high density of root generation sites, is assumed to be high enough to cause a significant rate of accumulation of fine-root necromass.

Distribution of fine-root necromass among zones

The average amount of fine-root necromass in 30 cm of soil, although it showed considerable variation within each zone (see standard deviations in Table 1), was differed considerably between the three zones (Table 1). The average fine-root necromass in the

Table 1 Amount of root biomass and necromass at three soil depths in the vegetation zones of a secondary mangrove forest.

Zone	Depth (cm)	N	Biomass (t/ha)	Necromass (t/ha)			Necromass/Biomass
			Fine root	Fine root	Non-fine root	Total	
Avicennia-	0–10	10	0.38 ± 0.34	3.62 ± 1.60	1.74 ± 0.69	5.36	9.53
Sonneratia	10–20	10	0.29 ± 0.26	3.28 ± 1.20	1.73 ± 0.94	5.01	11.3
	20–30	10	0.22 ± 0.19	3.04 ± 3.97	1.58 ± 1.02	4.62	13.8
total	0–30	10	$0.89 \pm 0.78^{\text{ns}}$	$9.94 \pm 4.60^{\text{b}}$	$5.05 \pm 1.61^{\text{c}}$	15.0	
Rhizophora	0–10	10	0.33 ± 0.33	5.74 ± 2.87	4.15 ± 5.38	9.89	17.4
	10–20	10	0.24 ± 0.26	7.12 ± 2.48	9.10 ± 8.09	16.2	29.7
	20–30	10	0.19 ± 0.17	8.21 ± 2.22	7.72 ± 7.21	15.9	43.2
total	0–30	10	$0.75 \pm 0.67^{\text{ns}}$	$21.1 \pm 6.1^{\text{b}}$	$21.0 \pm 14.6^{\text{b}}$	42.0	
Xylocarpus	0–10	15	0.53 ± 0.43	30.6 ± 17.1	12.8 ± 8.2	43.4	57.7
	10–20	15	0.50 ± 0.42	30.6 ± 14.5	15.9 ± 8.7	46.5	61.1
	20–30	15	0.34 ± 0.26	28.8 ± 11.6	13.7 ± 7.5	43.5	84.7
total	0–30	15	$1.37 \pm 0.94^{\text{ns}}$	$90.0 \pm 23.7^{\text{a}}$	$43.3 \pm 13.0^{\text{a}}$	133.3	

Root size was divided into fine roots (diameter $\leqslant$ 2 mm) and non-fine roots (diameter $>$ 2 mm). Different superscripts within a column indicate a significant difference ($P < 0.01$; least significant difference); ns = non significant difference.

Xylocarpus zone was 9.05- and 4.27-fold greater than that of the *Avicennia-Sonneratia* and *Rhizophora* zones, respectively, and this was statistically significantly different (two-way ANOVA, $F_{(2,102)} = 4.82$; $P < 0.01$). However, whilst the difference in the fine-root necromass was 2.12-fold higher in the *Rhizophora* zone than that in the *Avicennia-Sonneratia* zone, this was not statistically significant (Table 1). In contrast, the fine-root necromass at each respective depth was significantly different between the three zones (two-way ANOVA, $F_{(2,32)} = 5.34$; $P < 0.01$), increasing with increasing distance from the river (*Xylocarpus* > *Rhizophora* > *Avicennia-Sonneratia*).

The change in fine root necromass between zones is not simply due to a change in total fine root biomass, since there was no increase in the living fine root biomass between the *Avicennia-Sonneratia* and *Rhizophora* zones, and the higher average mass in the *Xylocarpus* zone than the other two zones was not statistically significant. The zonal distribution of fine-root necromass may then principally relate to the potential of fine-root decomposition in this forest. The slow rate of fine-root decomposition, compared to regeneration, will lead to the accumulation of fine-root necromass, as discussed above. However, the rate of fine-root decomposition was not measured in the present study and so this awaits confirmation. If for now we assume that the process of root decomposition is mainly performed by microbial activities in the soils, we can indirectly infer the rate of fine-root decomposition in this study site from the rate of CO_2 efflux from soil respiration reported by Poungparn et al[12] at the same study site. Inversely related to the soil respiration rate, the accumulation of fine-root necromass was obtained in the ranked order of *Xylocarpus* > *Rhizophora* > *Avicennia-Sonneratia* zones, in accordance with the observations seen here. According to Poungparn et al[12] the soil respiration rate was positively dependent upon the soil temperature, and is in accord with the highest and lowest soil temperatures being found in the *Avicennia-Sonneratia* and *Xylocarpus* zones, respectively, although these were only numerically and not statistically significantly different. That said, it is plausible, but not established, that the lower soil temperature in the *Xylocarpus* zone may restrict the microbial metabolism (soil respiration) related to fine-root decomposition sufficiently to shift the balance towards a greater necromass accumulation. Consequently, the fine root necromass/total fine root ratio significantly increased going from the *Avicennia-Sonneratia* to the *Rhizophora* and to the *Xylocarpus* zones, with average ratios for the 0–30 cm deep soil of 91.6, 96.6, and 98.5%, respectively. Alternatively, this can be expressed as the ratio of dead to live fine root biomass, which was 11.2, 28.1, and 65.7%, for the *Avicennia-Sonneratia*, *Rhizophora*, and *Xylocarpus* zones (Table 1). The high ratio in the *Xylocarpus* zone supports a higher rate of necromass accumulation than the other two zones. The pattern of accumulation of fine-root necromass may relate to the pattern of rising elevation (with respect to sea level) from the mangrove forest towards a terrestrial one.

In conclusion, a high portion of fine-root necromass was confirmed in this mangrove forest. It partly indicates the potential of the carbon sink of the forest. The zonal variation of fine-root necromass showed that the accumulation of fine-root necromass was higher in the inland zone than in the zone adjacent to the river edge. The pattern of distribution could potentially be indirectly explained by soil respiration which is temperature dependent.

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