A quantitative analysis of the root system of a mangrove, *Sonneratia caseolaris* (L.) Engler, with reference to the pipe model

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ABSTRACT The whole root system of a *Sonneratia caseolaris* tree of the edge of a secondary mangrove forest was carefully excavated using a water-pump. All roots were sorted by diameter and weighed. The root-weight distribution showed that the medium (10-20 mm) and large (20-30 mm) classes shared a large portion of root weight. We analyzed the relationship between the root diameter (*D*) and the number of roots (*F'*). A significant inverse linear relationship was obtained for the *F'*-*D* relationship. The slope was not statistically different from -2.0, suggesting that the root system of this *S. caseolaris* tree follows the pipe model (Shinozaki *et al.,* 1964a, b). The constant between total root weight (W_R) and the square of the stem diameter at ground level (D_0) was calculated. This proportional constant of *S. caseolaris* (0.025) was lower than that of *X. granatum* (0.051), which was formerly clarified to obey the pipe model theory (Poungparn *et al.,* 2002). We discussed the application of the pipe model theory to estimate the root weight of mangroves from the W_R-D_0^2 relationship's constant.

Key words: Root system, *Sonneratia caseolaris,* Root-diameter distribution, Pipe Model

INTRODUCTION

Mangrove biomass was studied in relation to the global warming phenomenon (Davis *et al.,* 1994; Ong *et al.,* 1995). However, only few studies on root biomass of mangroves have been reported (*i.e.* Briggs, 1977: Tabuchi *et al,* 1983: Komiyama *et al.,* 1989). More information on root biomass of mangrove trees is needed. *Sonneratia caseolaris* (L.) Engler is a well-known tree in the few mangroves that occupy the seaward zone (Macnae, 1968). Its peculiar root system has a combination of below-ground roots and pneumatophores. The root system of *S. caseolaris* has not been studied quantitatively.

The pipe model theory of tree form (Shinozaki *et al.,* 1964a and b, hereafter as Pipe Model) is a sophisticated theory that provides an advantage to root-weight estimation, because root weight can be calculated from the cross-sectional area of stem at the ground. To confirm the Pipe Model on the root system of a tree species, an analysis either on an individual basis or on a population basis can be adopted (Poungparn *et al.,* 2002). On an individual basis, the Pipe Model can be proved from the analysis of root-diameter distribution within each tree. On a population basis, it can be proved from the relationship between root weight and stem diameter at ground level for multiple trees in a focal population.

We analyzed the root system of a *S. caseolaris* quantitatively, and the Pipe Model was tested on an individual basis in this study. We also compared the root system of *S. caseolaris* with that of *X. granatum* formerly studied by Poungparn *et al.* (2002) in context of the Pipe Model.

STUDY SITE AND METHODS

This study was conducted at a secondary mangrove forest located on the Trat river estuary (12° 12'N, 102° 33'E), in Eastern Thailand along the Gulf of Thailand. We established a study plot of 40 x 110 m^2. In this plot, the tree density was 1,525 stem ha^{-1} (*DBH* > 4.0 cm), the average stem diameter at breast height (*DBH*) was 10 cm, and the average height (*H*) was 10.8 m. *Sonneratia caseolaris* and *Avicennia alba* were prevalent on the sea fringe, while *Rhizophora apiculata, R. mucronata,* and *Bruguiera gymnorrhiza* co-dominated in inland.

In the study plot, an individual of *S. caseolaris* (No. 602) was selected for the root study (Fig. 1). A *S. caseolaris* tree, two individuals of *A. alba* and a *R. apiculata* tree were present at distances of 2.6 - 4.5 m from the sample tree. For this sample tree, the stem diameter at ground level (D_0), at 30 cm height ($D_{0.3}$), and at the height of lowest living branch (D_B), was measured. The height from the ground to the lowest living branch (H_B) was also measured (Table 1).

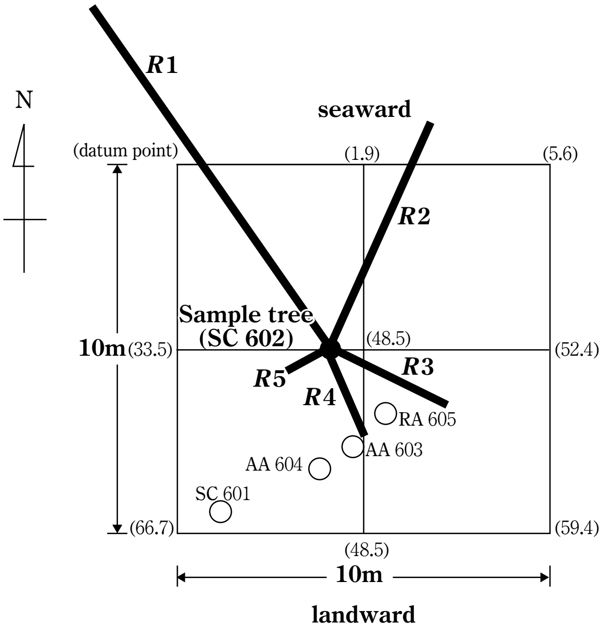

Fig. 1. Layout of the sample tree, *S. caseolaris* No. 602 (●). Four neighboring trees (open circle with tree number) were shown on the landward derection. Relative elevations (cm) of substrate are shown in parentheses at every 5 m from the datum point. Five first-order roots extending from the stem base of *S. caseolaris* are illustrated as R1, R2, R3, R4, and R5.

Table 1. Sizes and weights of *Sonneratia caseolaris* sample tree (No. 602).

Parameters	Size and weight
D_0	23.0 cm
$D_{0.3}$	16.1 cm
DBH	11.6 cm
D_B	11.0 cm
H_B	2.03 m
H	10.80 m
$W_{aboveground}$	41.36 kg
Below-ground root weight	11.29 kg
Pneumatophore weight	1.85 kg
T/R ratio	3.15

The above-ground part was cut at the ground level using handsaws, separated into stem, branch, and leaf, and weighed. Then, root excavation was carefully carried out by removing soil from roots using an engine pump (Honda G400). We manually washed all roots using seawater. The whole root system was carried to the laboratory of the Mangrove Operation Center No.1, Trat, of the Royal Forest Department.

The living roots were identified by the condition of the root surfaces, in terms of color, firmness, and freshness. We cut off the greenish parts of pneumatophores, which were conical, at to separate the parts which were buried under the soil in the field, and measured the basal diameter and height individually. Each pneumatophore was cut and separated at the points with diameters of 5, 10, 20, 30, 40 mm. Below-ground roots were also cut at the points with diameters of 5, 10, 20, 30,..., 100, 120, 140, and 160 mm and likewise sorted into diameter classes (0-5, 5-10, 10-20,..., 90-100, and 20 mm interval to 160 mm). The fresh root weight of each diameter class was weighed using an electric balance to 0.1 g (Scout II, Ohaus U.S.A). The fresh root weights were converted to dry weight by multiplying dry/fresh weight ratios. Approximately 200g of root sample taken from each diameter class was oven-dried (110° C for 48 hours) and weighed in order to obtain these ratios.

The volume of each pneumatophore was calculated from its basal diameter and height by assuming a conical shape. To estimae the volume of below-ground roots, the dry weight of each diameter class was divided by the root specific gravity (*SG* in g/cm^3). To obtain *SG*, approximately 50g of sub-samples were taken from each diameter class. The length and diameter of the respective roots of each sub-sample were measured to calculate volume. The *SG* was given by the ratio of dry weight to volume of sub-sample. The total volume of roots in each diameter class was used for calculating the number of 10 cm in length of root segments (*F'*).

RESULTS AND DISCUSSION

There were five primary below-ground roots branching from the stem base of the sample tree (Fig. 1). The lengths ranged from 1.25 to 10.47 m. A total number of 613 pneumatophores associated with the below-ground roots. Basal diameters and heights of pneumatophores ranged from 0.1 - 4.2 cm and 0.6 - 65.7 cm, respectively. Total root weight of the sample tree was 13.15 kg (Table 1).

The root-weight distribution of the sample tree showed a bias to medium (10-20 mm) and large (20-30 mm) sized roots. The fine and small roots (0-5 mm), and very large roots (>50mm) had relatively small proportions. One reason for the large portion of the medium and large roots is that the below-ground roots, which were mostly medium and large in size, shared the most of the total root weight (85.86%). The below-ground roots extended horizontally, anchoring the tree to the substrate and supporting the above-ground parts of the tree. These roots also connected pneumatophores that branched vertically from the below-ground roots. An abundance of medium-sized roots was found in other mangroves, *R. stylosa* and *B. gymnorrhiza* (Komiyama *et al.,* 1989). They discussed the existence of prop roots or cable-like roots for a reason of abundance in the medium-sized roots.

In logarithmic coordinate, a significant inverse linear relationship was observed ($P<0.01$) between the number of root (*F'*) and the root diameter (*D*) (Fig. 2). The slope of the *F'*-*D* relationship (Equation 1) was not statistically different from -2.0 (*t-test*, $P<0.05$).

$$F' = 108947\, D^{-2.325}, \quad R^2 = 0.9052 \qquad (1)$$

The *F'*-*D* relationship reveals an overall tendency of root-diameter distribution that the larger in root diameter, the smaller in number of root. Because the slope of *F'*-*D* relationship was statistically non-different from -2.0, the total cross-sectional area was identical for all root size classes. Thus, the root system of *S. caseolaris* is considered to follow the Pipe Model on an individual basis.

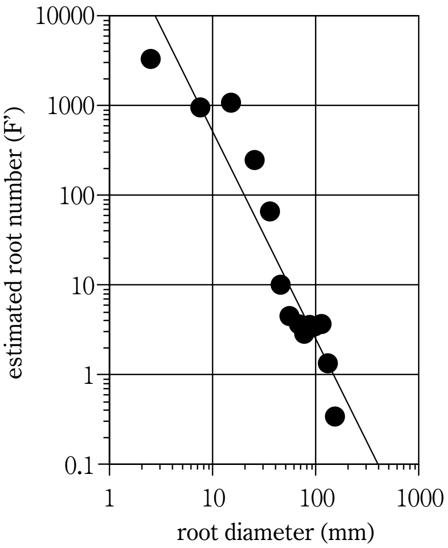

Fig. 2. Root-diameter distribution of *S. caseolaris* in relation to root diameter and estimated root number F'. The regression line shows an inverse relationship with the slope of -2.0. The central diameters of each diameter class were used for plotting.

The value of -2.0 for the slope of *F'*-*D* relationship was originally clarified for some trees of cool temperate forests (Shinozaki *et al.,* 1964b), and those of beach forests (Yoda & Satoo, 1967) of Japan. The six root systems of *X. granatum* also gave a value of -2.0 for the slope of *F'*-*D* relationship, and followed the Pipe Model (Poungparn *et al.,* 2002). It is noteworthy that the peculiar root system of mangroves can be simply explained by the Pipe Model.

From the single sample tree of *S. caseolaris* in this study, it was clarified that the root system of this *S. caseolaris* tree obeyed the Pipe Model on the individual basis. Although we can not directly prove the Pipe Model on the population basis for root system of *S. caseolaris* in the present study, we theoretically hypothesize that the inclination of the allometric relationship between total root weight and the square of stem diameter at ground level is regarded to be 1.0 (Shinozaki *et al.,* 1964a, b) as shown by Equation 2.

$$W_R = a(D_0^2)^{1.0} \qquad (2)$$

The coefficient a of Equation 2 refers to the proportional constant between root weight and the square of stem diameter at ground level. The coefficient a of *S. caseolaris* was calculated as 0.025, while the average value of coefficient a for six *X. granatum* was 0.051 (Poungparn *et al.,* 2002). This implies that the root weight of *S. caseolaris* is about half of that of *X. granatum* with the same stem diameter. The root system of a mangrove tree mechanically supports its above-ground weight on the soft substrate. The low root weight of *S. caseolaris* is partly explained by the low root specific gravity of *S. caseolaris* (0.1519 - 0.1930 g/cm^3) in comparison with *X. granatum* (0.292 - 0.371 g/cm^3). The relatively high T/R ratio of *S. caseolaris* (3.15, Table 1) also supports the low root weight of this tree.

In conclusion, we confirmed that a root system of *S. caseolaris* followed the Pipe Model on the individual basis. The fitting of *S. caseolaris* root system to the Pipe Model makes the application for root-biomass estimation in mangrove forests possible, because the total root weight of a tree can be estimated by the stem diameter at the ground level using the proportional constant. However, proving the applicability of the Pipe Model on the population basis for *S. caseolaris* root system should be done by sampling more.

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