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Structural complexity and disturbances: indicators of mangrove forest in Berau Delta, East Kalimantan, Indonesia

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Abstract: Common types of disturbing factors faced by mangrove forests are natural and anthropogenic disturbances. These factors had led to a decline of the mangrove forests area, lessening its role as land stabilizer from coastal damages and functions in providing fisheries habitat, shelter and food for marine organisms. In this study, mangrove roots structure and tree characteristics were studied to investigate their influence to the disturbance factors; the distance to natural disturbances (open water) and anthropogenic disturbances (e.g. villages). A significant increase in tree height and a decrease in tree density was found when mangroves were farther located from natural disturbance. In addition, the roots branching order was found correlated with the distance to natural disturbances, while root diameter increased relative to the distance to anthropogenic disturbances. The results of this study reveal the potential use of tree and root complexity as indicators related to disturbance factors in the mangrove forest.

1 Introduction

The Berau Delta is characterized by a high density of botanical species (Bodegom et al., 1999) where various mangrove and non-mangrove species can be found in this area. The main species are *Rhizophora sp., Xylocarpus sp., Bruguiera sp., Sonneratia sp., Avicennia sp.* and *Nipa fruticans*. These resources are utilized by the villagers for housing material, firewood, fishing stakes, while the delta areas are used for human settlements and brackish fish ponds for fish farming. The great ecological and economical potential offered by mangrove forest is unfortunately in a serious decline by the impact of several disturbing factors. The declination was due to both natural and anthropogenic impacts (Jason Broshear, 2005). For example, high population pressure in Java had caused more than 50 percent of the mangrove areas in the island to be heavily exploited due to the land development for human settlements and conversion for fish farming activities (Choong et al., 1990). Besides anthropogenic disturbance, mangroves also concerned with the natural disruption, such as hurricane, tsunami, tidal wave and soil erosion which can affect the mangrove ecosystems.

Most researches have been carried out on the botany and ecology of mangrove, but less is known about the interactions with the environment. Therefore this study was done to investigate the relationship between both mangrove disturbances with tree structure and root complexity.

Holdridge (1967) had described complexity by high number of species, stem density, basal area and height of trees while Brooks and Bell (2005) added the below-water measurement (e.g., roots) in explaining the complexity of mangrove forest. In this study both above and below-water parameters were used to check its relation with the distance to the disturbance factors.

2 Materials and methods

2.1 Study area

The study was carried out at the Berau Delta, East Kalimantan, Indonesia (Figure 1). It is located between 1° 00' 00" to 2° 33' 00"N and 117° 00'00" to 119° 00' 00"E. The Delta consists of five villages with the area about 227,138 ha. The tropical season was influenced by West monsoon from November to April and East monsoon from May until October with mean temperature up to 31°C and average rainfall of 298mm per month.

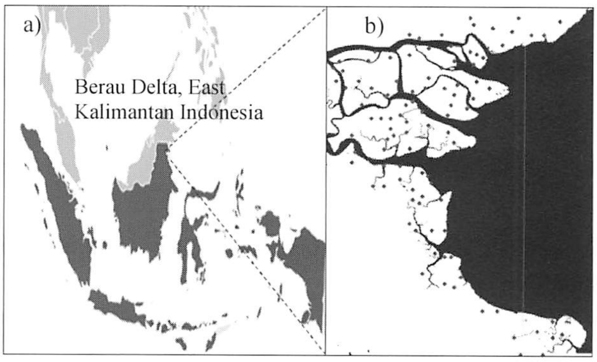

Figure 1: a) Indonesia map and b) Location of study area (Berau Delta, East Kalimantan) with black dots indicating the study sites

2.2 Tree composition

We had chosen fifty sampling points through a random selection based on a gridded map. In each point a 20x20m plot was setup and information on mangrove stands (species, tree height, diameter at breast height (dbh), geographical coordinates, percentage of crown cover in the plot, number of seedlings and saplings) were recorded. An electronic laser distance meter (Leica Distro D2 with ±1.5mm accuracy) was used to

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measure tree height in meter (m). Tree dbh was measured using diameter tape and the geographical position of the central point of each plot was recorded using a hand-held GPS Garmin 60CX 12-channel receiver. The average percentage of canopy cover was visually estimated by three observers referring to the Estimated Foliage Cover generated by Richard et al. (1955). Trees were defined as individual with a height ≥1.5m; while saplings were <1.5m and seedlings were ≤50cm. The number of saplings and seedlings were counted individually over the 400m^2 plot and data was collected from October until December 2009.

2.3 Root composition

In each 20x20m plot setup for quantifying the tree composition, another five 1m^3 collapsible quadrats made of PVC pipe were set up to determine the root density (Figure 2). In these small plots, root composition (root length, root diameter and branching order) were measured. Prop roots branching pattern were recorded with a first branching order is the first root sprouts from the main tree trunk and when the new roots branching off from the first root, it was recorded as the second order etc. These root composition data were used to obtain the density and structural complexity of each plot. We assumed that the structural complexity of the area would increase if the root density, root length, root diameter and branching order increased.

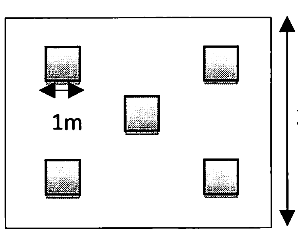

Figure 2: A 20x20m plot (big square) was setup in each sampling point to measure tree composition. In five small subplot of 1x1m (small square) roots composition data was recorded.

Besides field work, satellite image analysis of TM Landsat-7 was also carried out using ERDAS software. Measurement of the distance to nearest village and open water (big channel) were determined using this tool.

2.4 Analysis procedures

Distance to disturbance sources were tested in relation to tree characteristics (tree density, height and dbh), tree cover (species number, percentage of estimated crown cover, number of saplings and seedlings), and root characteristics (branching pattern, root density, length and diameter). All variables were first tested using Spearman's rho (rs). Then a regression analysis was done to check either the significant variables have a positive or negative relation with a disturbance factors.

3 Results

Total of 822 trees from 17 species were recorded in which *Rhizophora apiculata* was found as a dominant species with an average tree height and dbh of 13.9m and 17.6cm respectively (Figure 3). The results of correlation analysis of tree and root structure of surveyed plots are summarized in Table 1.

Based on the result, only tree height and density, root diameter and branching pattern showed significant relationship to disturbances. A multiple regression analyses using the Enter method was done to test the relationship between multiple independent variables (both disturbances factors) and all dependent variables. Unfortunately, it did not show any significant relationship to each variables tested.

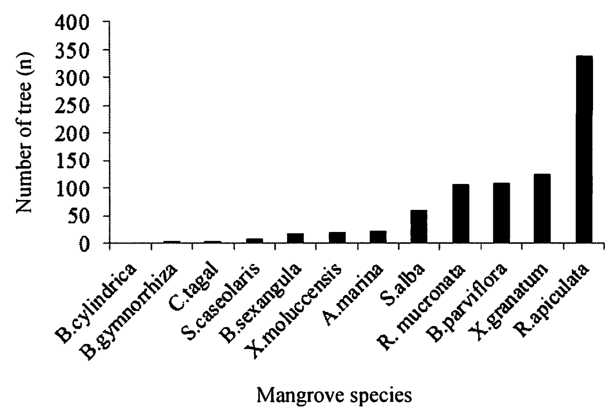

Figure 3: Total number of mangrove trees per species found over all 50 surveyed plots.

4 Discussions

An increase in tree height and a decrease in tree density were found when mangroves were farther from natural disturbance. Distant from the main water sources e.g., sea or big river had triggered different mangrove species composition due to the different salinity and inundation factors (Chapman, 1975). For example, in Apar Nature Park, Kalimantan, the average tree height of seaward area is lower than at landward edge. *Rhizophora sp.* located near to landward edge was found 10m higher than *Avicennia sp.* with a height of 30m and located at seaward area (Sukardjo, 1994). Wave and currents can directly or indirectly change the structural characteristic and functions of mangrove ecosystem. In addition, high and low tidal range could also affect mangrove root system. Prop roots of *Rhizophora sp.* with a wide tidal range will extend far above the soil surface while lower

Table 1: Summarizing table of correlation results between distances to disturbances and various dependent variables, using Spearman's rho, in the Berau Delta mangrove area.

	Distance to natural disturbance (open water)			Distance to anthropogenic disturbance(village)		
<u>Tree characteristics</u>	rs	p	n	rs	p	n
Tree density(N/0.04ha)	-0.43	0.007	38	-0.14	n.s	38
Tree height(m)	0.35	0.03	38	0.22	n.s	38
Tree diameter(cm)	0.25	n.s	38	0.1	n.s	38
<u>Tree cover and density</u>						
Species number(N)	0.06	n.s	50	-0.12	n.s	50
Crown cover (%)	0.26	0.07	50	0.02	n.s	50
Saplings number(N/0.04ha)	-0.19	n.s	50	-0.15	n.s	50
Seedlings number(N/0.04ha)	-0.46	n.s	50	0.89	n.s	50
<u>Root characteristics</u>						
Root density(m^2)	-0.14	n.s	32	0.23	n.s	32
Root length(cm/m^2)	-0.04	n.s	32	-0.21	n.s	32
Root diameter(cm/m^2)	-0.05	n.s	32	-0.43	0.01	32
Branching pattern(N)	0.51	0.008	25	0.12	n.s	25

roots were significantly found in a narrow tidal range. matter were probably accumulated in the soil (Carter et al., 1973) and increasing the productivity and standing biomass (Alongi et al., 2000). For that reason, we would find a greater tree density compared to the wave sheltered area which contained less nutrients sedimentation at the seaward margin in Berau Delta area. Besides having a greater tree density, the trees in this area were found lower in height. This was caused by natural disturbance such as wave action and tropical storm that attack and had limited the development of the tree (Egler, 1952). Therefore we would expect trees that were exposed to disturbances are generally smaller in diameter and height compare to the sheltered area which has lower disturbance effects.

The root branching pattern influence the distance to natural disturbance. Referring to Brown and Lugo (1982) the physical complexity decreased because of wave interruption which this factor could slower the development and growth of the roots. Hence the prop roots are found difficult to anchor in the sandy and muddy area near seaward. As a result, more complex root structure was found further away from natural disturbance. The presence of crab and predator are another factor of unsuccessful growth of the roots hence decreases the root complexity. Crab attacked the unbranched and immature prop roots before it can penetrate the substrate and reduce the survival rate of the roots (Feller and Mathis, 1997). Therefore, in the area near to water, less prop root were found survived compare to undisturbed areas.

At the wave exposed sites, micro nutrient and organic

Salinity is one of the factors that caused the erect roots of *Avicennia sp.* and *Sonneratia sp.* could accommodating the seaward area and this type of roots are relatively smaller in sizes compared to the prop root of *Rhizophora sp.* and plank root of *Xylocarpus sp.*. Besides that, from personel observations, bigger roots were found 20 to 50m from the village in Berau delta. As fisherman villages located near the water, it was exposed to the sea wind and tidal inundation. The vegetation barrier offered by mangrove especially from Rhizophora tree species helps to shelter the community from tsunamis and wave action where usually in this area bigger trees with strong roots are found. For example, in east India, the villages situated behind mangrove forests were afforded greater protection than those along the open beach.

In conclusion, this study revealed the significant influence of the distance to disturbances on the changes in tree and roots characteristics. However, the method could be improved by including environmental factors such as salinity, altitude, rainfall to yield better explanation of complexity.

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