

# Forest structure of a subtropical mangrove along a river inferred from potential tree height and biomass

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## ABSTRACT

The hypothesis was tested that potential tree height and biomass in mangroves decrease downstream with the tidal gradient along the Okukubi River in Okinawa Island, Japan. The mangrove stands consisted of *Bruguiera gymnorrhiza* (L.) Lamk. and *Kandelia obovata* (S., L.) Yong (Rhizophoraceae). Four sites were selected considering the distance from the mouth of the river. Soil salinity increased downstream, while soil total nitrogen content decreased. The soil redox potential did not vary along the river. Maximum gross photosynthesis and tree height for each species decreased downstream. The potential tree height ( $H_{\max}$ ) inferred from the stem diameter ( $D_{0.1}$ )–tree height ( $H$ ) relationship ( $1/H = 1/aD_{0.1}^h + 1/H_{\max}$ ;  $a$ ,  $h$ , coefficient) in each species decreased downstream. The tree density ( $\rho$ )–mean tree size ( $D_{0.1}^2 H$ ) relationships ( $D_{0.1}^2 H = K\rho^{-\alpha}$ ;  $K$ ,  $\alpha$ , coefficient) determined for four sites revealed that the mean tree size at any given tree density decreased downstream, which indicates the decrease of potential biomass. Furthermore, an index for biomass ( $D_{0.1}^2 H\rho = K$ ) was homogeneous within a site regardless of tree density, i.e. the value of  $\alpha$  at each site did not differ significantly from 1.0 ( $p > 0.05$ ). The decreases in potential tree height and biomass may be partially ascribed to the stressful environments at the downstream sites characterized by high salinity (>2.6‰) and nitrogen-poor soils (<0.25 ppt) in our study area.

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## 1. Introduction

Mangrove communities show gradual changes in forest structure along tidal gradients. For instance, changes in tree height (Lugo and Snedaker, 1974) and biomass (Sherman et al., 2003) have been reported. These changes may be ascribed to stunting in plant growth in stressful environments due to high salinity and poor nutrient conditions (Cheeseman and Lovelock, 2004; Lovelock et al., 2006; Naidoo, 2006). The potential tree height and biomass would be decreased with increasing such stress factors along the tidal gradients.

We tested this hypothesis in a mangrove forest, which mainly consisted of *Bruguiera gymnorrhiza* (L.) Lamk. and *Kandelia obovata* (S., L.) Yong (Rhizophoraceae), in the estuary of the Okukubi River, Okinawa Island, Japan. These species are dominant in the mangrove forests of East Asia at high latitudes (Hosokawa et al., 1977; Lin, 1999). We evaluated the forest structure on the basis of tree censuses at different locations in the estuary. We also

quantified maximum leaf photosynthesis at these various locations in the estuary to elucidate the mechanism underlying the changes in forest structure. Maximum leaf photosynthesis of *B. gymnorrhiza* and *K. obovata* reportedly decreases gradually with increasing salinity from 0 to 500 mM NaCl (Kawamitsu et al., 1995; Kao and Tsai, 1999; Takemura et al., 2000). Furthermore, the combination of high salinity and poor nitrogen reduces leaf photosynthesis by disrupting nitrogen uptake (Kao and Tsai, 1999).

## 2. Methods

### 2.1. Field sites

This study was conducted in a mangrove forest along the Okukubi River in Okinawa Island, Japan (26°27' N, 127°56' E, Fig. 1). On the basis of the 1994–2003 data obtained at the Okinawa Meteorological Observatory, the mean monthly minimum and maximum temperatures were estimated to be 16.6 °C (January) and 28.7 °C (July), respectively. Rainfall was more than 100 mm month<sup>-1</sup> throughout the year, and the mean annual rainfall was 1978 mm year<sup>-1</sup>. The mangrove forest consisted mainly of *B. gymnorrhiza* (L.) Lamk. and *K. obovata* (S., L.) Yong. A few individuals of *Rhizophora stylosa* Griff. and *Lumnitzera racemosa* Willd. were also noted.

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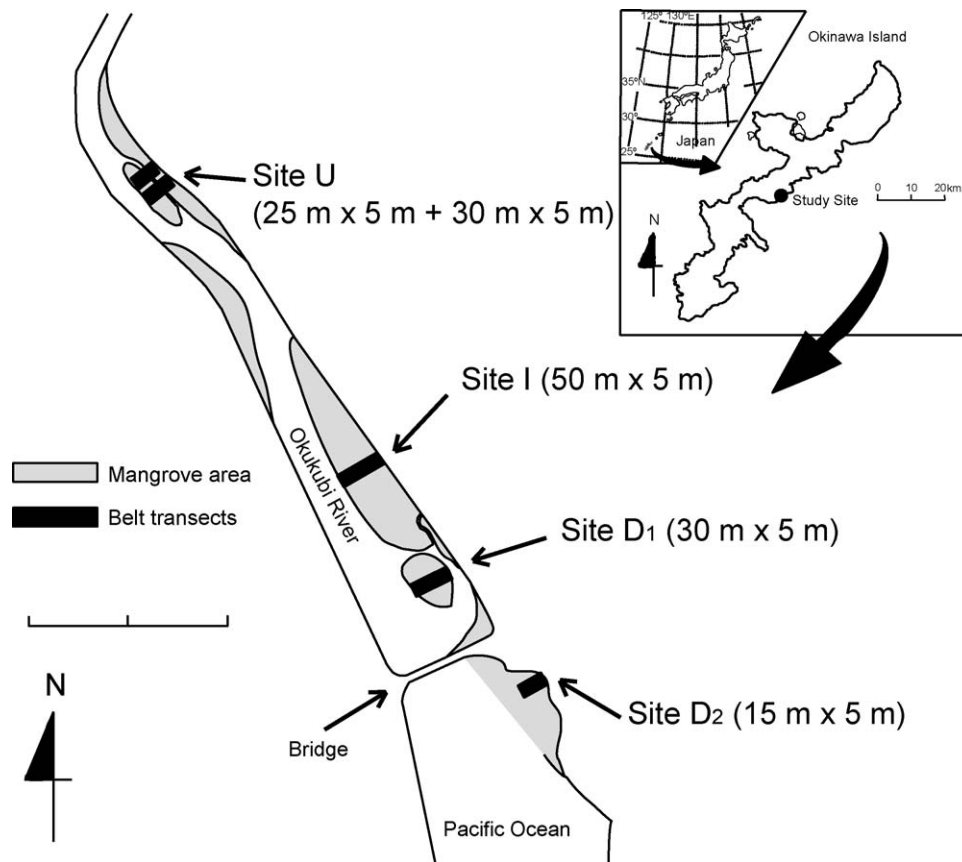


Fig. 1. Map of the study area.

Four sites were selected considering the distance from the mouth of the river (Fig. 1). Site U consisted of two belt transects located close to each other. Sites I, D<sub>1</sub>, and D<sub>2</sub> consisted of a single belt transect each. Each 5 m-wide belt transect traversed the mangrove forest perpendicularly to the river and was divided into 5 × 5-m subplots. The total lengths of the belt transects were 55 m (Site U), 50 m (Site I), 30 m (Site D<sub>1</sub>), and 15 m (Site D<sub>2</sub>).

## 2.2. Tree census

All individual trees within the belt transects were counted and measured for height ( $H$ , m) and stem diameter at  $H/10$  ( $D_{0.1}$ , cm) in November 2004. We used the stem diameter at  $H/10$ , rather than at breast height (DBH), as the measure of stem diameter. This was necessary because the height of short trees under the stressful conditions in mangroves often never reach breast height (1.3 m above the ground); therefore, the DBH of these stunted trees cannot be measured (Hogarth, 1999; Ross et al., 2001; Coronado-Molina et al., 2004). Thus, using  $H/10$  allows us to measure the stem diameters of such short trees (Ogawa and Kira, 1977; Hagihara et al., 1993; Khan et al., 2005; Suwa et al., 2008).

To measure soil salinity (%), soil pore water was extracted from three points in each subplot using a plastic tube connected to a 500-mL cylinder, taking care to avoid mixing the pore water and surface water (McKee et al., 1988). However, this method could not be applied in some plots where the soil consisted mainly of sand. In such cases we dug holes to collect the soil pore water. Salinity of the collected pore water was immediately measured in the field with a salinometer (ES-421, Atago, Japan). The soil redox potential (mV) was simultaneously measured at a depth of 10–20 cm in each subplot using an electrode oxidation–reduction potential meter (RM 20P, TOA, Japan). Three soil cores were sampled from the

topsoil in each subplot (0–10 cm deep) to measure total nitrogen content (ppt). The soil samples were dried to a constant mass at 80 °C and powdered before measuring total nitrogen content with a CHN-coder (JM 10, J-Science Lab, Japan).

## 2.3. Photosynthetic measurement

Photosynthetic photon flux density (PPFD)–net photosynthesis curves were determined for *B. gymnorrhiza* and *K. obovata* in May 2006 with a portable photosynthesis system (LI-6400, LI-COR, USA). Seven sun leaves per species were chosen at each site. The PPFD ( $I$ ) inside the chamber was regulated at eight levels (1600, 800, 400, 200, 100, 50, 25, and 0  $\mu\text{mol photon m}^{-2} \text{s}^{-1}$ ) using an LED light source (6400-02B, LI-COR, USA). Leaf temperature was controlled within the range of 25–27 °C, considering the ambient air temperature during the measurement period. CO<sub>2</sub> concentration was regulated at 370 ppm.

## 2.4. Models

To quantify the potential tree height for each species at each site, the stem diameter ( $D_{0.1}$ )–tree height ( $H$ ) relationship was examined with the generalized allometric function (Ogawa and Kira, 1977)

$$\frac{1}{H} = \frac{1}{aD_{0.1}^h} + \frac{1}{H_{\max}} \quad (1)$$

where  $a$  and  $h$  are the coefficients, and  $H_{\max}$  is the potential tree height. In a previous paper (Suwa et al., 2008), the value of  $h$ , i.e. the ratio of the relative growth rate of  $H$  to that of  $D_{0.1}$  in small trees, could be assumed to be one. In the present study, the value of  $h$

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