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Species composition, biomass, and net primary productivity of mangrove forest in Okukubi River, Okinawa Island, Japan

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ABSTRACT

Species composition and productivity of mangrove forest at Okukubi River, Okinawa Island, Japan, were examined during a period from February 2010 to January 2013. Species composition, above and below-ground biomass changes, and litterfall production were measured. *Bruguiera gymnorrhiza* has maintained its dominance (93.1%, relative dominance) of the stand. Mean mortality of trees was 16.4%, due to frequent attack of typhoons creating tree fall and hitting of other trees. The total above and below-ground biomass of the stand was 162.7 and 125.1 Mg ha^{-1}, respectively. Among the total aboveground biomass of the trees, 7.2% was allocated to leaf, 69.2% to stem, and 10.1% to branch. In case of species wise contribution of biomass allocation, *B. gymnorrhiza* showed the highest score and *R. stylosa* the lowest. Mean annual litterfall was 11.8 Mg ha^{-1} yr^{-1}, with the maximum litterfall in summer and minimum in winter. The mean aboveground biomass increment and aboveground net primary productivity was 8.5 and 28.6 Mg ha^{-1} yr^{-1}, respectively. Total net primary productivity was estimated to be 42.5 Mg ha^{-1} yr^{-1}. This study revealed that mangrove forest with similar height and diameter produced different biomass production with different basal area. In the present study, the root biomass was large and the mean ratio of above/belowground biomass was estimated to be 1.3. It is emphasized that mangrove forests growing at the northern limit of their biogeographical distribution showed high biomass and net primary production indicating its ecological significance.

1. Introduction

Mangrove forests are among the world's most productive ecosystems, as well as unique wetland ecosystems in intertidal coastal regions of the tropics and subtropics (Lugo and Snedaker, 1975; Nagarajan et al., 2008). Mangroves are also important contributors of nutrients to estuarine and inshore productivity through litterfall. Their litterfall is a valuable indicator of their productivity and it is the most easily measured component of total net primary productivity (Day et al., 1987; Mackey and Smail, 1995). Biomass and net primary productivity of mangrove forest have been studied previously in different mangrove forest across the world (e.g., Putz and Chan, 1986; Day et al., 1996; Saintilan, 1997; Komiyama et al., 2000) and the purpose of biomass estimation and productivity of mangrove forest are mainly in terms of ecosystem management and evaluating carbon stock (Tamai et al., 1986; Komiyama et al., 1987, 2000). However, biomass production depends on the interaction between edaphic, climatic and topographic factors of the specified area and also there is some methodological differences in calculation of net primary productivity.

Our study was conducted in a mangrove community, which is occupied mainly by *Bruguiera gymnorrhiza* (L.) Lamk., and a few individuals of *Kandelia obovata* Sheue, Liu and Yong, and *Rhizophora stylosa* Griff., all in the family Rhizophoraceae, the most important family of true mangroves. Few previous studies examined the allometry and self-thinning relationship, forest structure, and phenology of *B. gymnorrhiza* in this area (Suwa et al., 2009; Deshar et al., 2012a,b; Kamruzzaman et al., 2016), and there have been no

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previous studies which examined net primary productivity of the mangrove forests in this area.

For the majority of mangrove studies, net primary productivity was measured without including dead tree biomass and litterfall has been measured for a short time period (Christensen, 1978; Day et al., 1987; Hernádez et al., 2011). However, in this study, we examined three years of data for each of the components and took tree mortality during calculation into account of net primary productivity. In this context, growth and mortality rates of trees in a *B. gymnorrhiza* dominated mangrove forest are presented in this paper. Stand structure, species composition, above and below ground biomass, net primary productivity, and their relationship to different parameters are also examined.

The largest area of mangroves occurs in the latitudes from 0° to 10° zone and the smallest area in the 30° to 40° latitudes combining north and south latitudes within each zone. Similarly the average aboveground biomass ranged from 283.6 Mg ha^{-1} near the equator to 104.2 Mg ha^{-1} in the 30°–40° latitudinal zone (Twilley et al., 1992). Komiyama et al. (2008) also reported that in low latitudes, primary or mature mangrove forests generally have high above-ground biomass. Consequently, as an additional objective, we hypothesized that aboveground net primary productivity (AGNPP) of mangroves near the low latitude zone is higher than the higher latitudinal zone. To test the hypothesis, we have assembled and analyzed data from published sources pertaining to mangrove forest AGNPP and latitude of the mangroves.

2. Materials and methods

2.1. Study site and sampling method

The study was conducted in a *B. gymnorrhiza* dominated mangrove forest along the Okukubi River (26°27′N, 127°56′E) on Okinawa Island, Japan, over three years from February 2010 to January 2013 (Fig. 1). Meteorological data were obtained from Nago Meteorological Station, Nago, Okinawa, Japan, from February 2010 to January 2013 (i.e., over the time period during which the field work was conducted). Mean annual air temperature was (22.7 ± 0.2)° C (SE). Rainfall varied throughout the year but exceeded 100 mm month^{-1} in most months. Annual total rainfall was 2482.2 ± 145.7 mm yr^{-1}. The mean monthly air relative humidity was (75.1 ± 0.1)%. Monthly maximum wind speed varied from the lowest value of 9.4 m s^{-1} in April 2011 to the highest of 36.2 m s^{-1} in May 2011. Mangrove forests along Okukubi River covers very narrow place as compared with other mangrove area in the tropics. So there is not any distinct species zonation within the mangrove forest, nor difference in habitat condition in the stands.

We established a non-continuous (215 × 5 m) belt-transect and divided it into 43 plots (5 × 5 m each) in the mangrove forest (Fig. 1). Each 5 m wide belt transect traversed the mangrove forest parallel to the river and was divided into 5 × 5 m plots. The total length of transects area are as follows: A: 20 m, B: 20 m, C: 40 m, D: 35 m, and E: 100 m, respectively. All trees in the study plots were numbered and height (H), stem diameter at $H/10$ ($D_{0.1H}$), and diameter at breast height (DBH) were measured. Tree height (H) and stem diameter at $H/10$ ($D_{0.1H}$) for *B. gymnorrhiza* and *K. obovata*, and DBH for *R. stylosa* were measured in August 2010, 2011, and 2012. *R. stylosa* tree has stilt roots from their main stem and also aerial root comes from lower branches so it is very difficult to fix the position of $H/10$ to measure $D_{0.1H}$ rather than DBH, so we measure DBH only for *R. stylosa* trees. Structural indices were calculated: complexity index, I_c: number of species × density × basal area × mean height ×10^{-5}; and importance value, I_v: relative density + relative frequency + relative dominance (Cintron and Schaeffer-Novelli, 1984).

2.2. Biomass estimation

The leaf, stem, branch, and above-ground mass of each tree of *B. gymnorrhiza* and *K. obovata* were estimated using allometric model established by Deshar et al. (2012b) and Khan et al. (2009), respectively. The belowground root mass of each tree of *B. gymnorrhiza* and *K. obovata* were estimated using allometric relationships established by Komiyama et al. (2005) and Hoque et al. (2011), respectively. The leaf, stem, branch, aboveground stilt root, above-ground total mass, and belowground root mass of each tree of *R. stylosa* was estimated using allometric relationships between DBH and mass, established by Comely and McGuinnes (2005). Individual component's mass calculation and its increment for each tree were estimated using the same allometric equation.

2.3. Litter collection

Fallen litter was collected using 1-mm mesh litter traps with collection area of 0.2 m^2. Two litter traps were placed in each 5 × 5 m plot at <1 m high from the ground to avoid tidal water, i.e., a total of 86 litter traps were placed within the 43 plots. The litter traps were emptied monthly; the collected litterfall was kept in a cotton bag and carried to the laboratory immediately, then it was separated into leaf, stipule, branch, flower bud, flower, and propagule. Each litterfall components were dried at 80 °C for 48 h, desiccated at room temperature, and then weighed using a digital balance (EK-600H, A & D Co., Ltd., Tokyo, Japan).

2.4. Net primary production

Net Primary Production (NPP), ΔP_n (Mg ha^{-1} yr^{-1}), was estimated by the summation method of Ogawa (1977) and Matsuura and Kajimoto (2013) as follows:

$$\Delta P_n = \Delta y + \Delta L + \Delta G$$

where Δy (Mg ha^{-1} yr^{-1}) is biomass increment disregarding tree mortality, ΔL (Mg ha^{-1} yr^{-1}) is total dead matter, which is sum of total litter production and amount of dry matter due to tree mortality, and ΔG (Mg ha^{-1} yr^{-1}) is amount of grazing. We do not account for direct herbivory in this study, therefore, ΔG is negligibly small in the present study area, and ΔG is ignored in the current study.

3. Results

3.1. Mangrove structure and composition

The mean densities of *B. gymnorrhiza*, *K. obovata*, and *R. stylosa*, were 7116, 595, and 93 ha^{-1}, respectively, and the mean heights (±SE) were 6.9 ± 0.3, 5.3 ± 0.2, and 5.4 ± 0.4 m as of August 2012. The mean $D_{0.1H}$ of *B. gymnorrhiza* and *K. obovata* (±SE) was 9.3 ± 0.5 and 6.8 ±0.4 cm, respectively, and the mean DBH (±SE) of *R. stylosa* was 7.6 ± 0.8 cm. The preponderance of *B. gymnorrhiza* gives rise to a high value of its importance value index (I_v = 274.4) during the study period (Table 1). The importance value index for *K. obovata* and for *R. stylosa* were 20.9 and 4.7 respectively. The specific density and relative dominance of *B. gymnorrhiza* in the studied area was 7116 ha^{-1} and 93.1%, respectively as of August 2012. Based on the specie's importance value, *B. gymnorrhiza* was the principle species in the mangrove forest along the Okukubi River, Okinawa, Japan. Tree density decreased with increasing age of the stand. The mortality rate of *K. obovata* was the highest than other species.

Structural characteristics of the mangrove forest are presented in Table 2. The high value of the complexity index (I_c = 60) indicates especially the high density of the stand. Complexity