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Article

Estimation of aboveground biomass in a *Rhizophora stylosa* forest with densely developed prop roots in Pohnpei Island, Federated States of Micronesia

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Abstract: Aboveground biomass and productivity of a *Rhizophora stylosa* forest, which generally develops along the seaward edge of the coral reef type mangrove forests, were described using three times of census data from a permanent plot on a small island in the lagoon of Pohnpei Barrier Reef Island, the Federated States of Micronesia.

As the aboveground root biomass had been underestimated by the existing allometric equations because of densely developed prop roots, we estimated it by detailed measurement. The ratio of prop root biomass was estimated at 58% of aboveground biomass of *R. stylosa* in the plot.

Total aboveground biomass including that of the other species increased from 229 t ha^{-1} in 2003 to 254 t ha^{-1} in 2011, indicating 3.2 t ha^{-1} yr^{-1} of annual increment. These values are apparently smaller than those of the mangrove forests fringing the main island of Pohnpei. The differences seem to be caused by the environmental stress induced by high salinity of soil water in this *R. stylosa* habitat.

Keywords: Aboveground biomass, Mangrove, Pohnpei Island, Prop root, *Rhizophora stylosa*

Introduction

Understanding forest biomass and productivity is useful for resource management and evaluation of the ability of carbon storage in the region. Some allometric equetions to estimate aboveground biomass of mangrove species have been proposed in the Asia-Pacific region (e.g. Komiyama et al. 1988, 2008; Poungparn et al. 2002; Ong et al. 2004; Soares and Schaeffer-Novelli 2005).

The *Rhizophora stylosa* community, which is characterized by high density of prop roots, generally develops at the seaward margin of the coral reef type mangrove forests in the Asia-Pacific region. The allometric equations for *Rhizophora* spp. have been developed by Komiyama et al. (1988), Ong et al. (2004), and others. However, the equations cannot be applied for the *R. stylosa* community because of the high density of prop roots.

This study aims at clarifying the aboveground biomass of the *R. stylosa* community on a small island in the lagoon of Pohnpei Barrier Reef Island, the Federated States of Micronesia, by means of actual measurement for the prop roots and existing allometric equations for the other plant parts using the data obtained from a permanent plot. We also reveal the forest dynamics and productivity on the basis of census data for eight years in the permanent plot and discuss the differences with the major mangrove communities of the main Island and the environmental factors induced the differences.

Study site

Outline of the study area

Pohnpei Island, located at lat. between 6°45′ and

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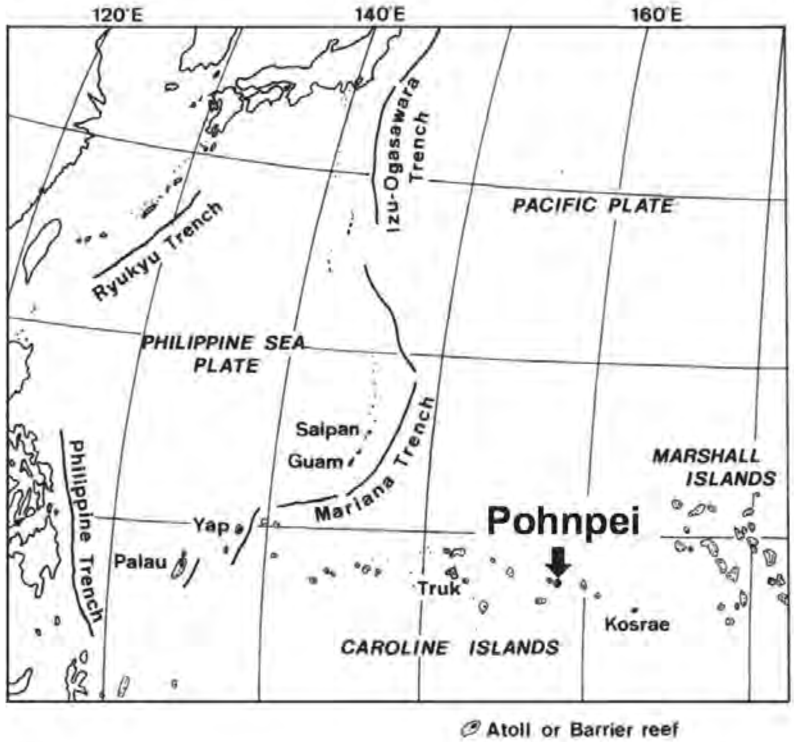

Fig.1 Map showing the location of Pohnpei Island

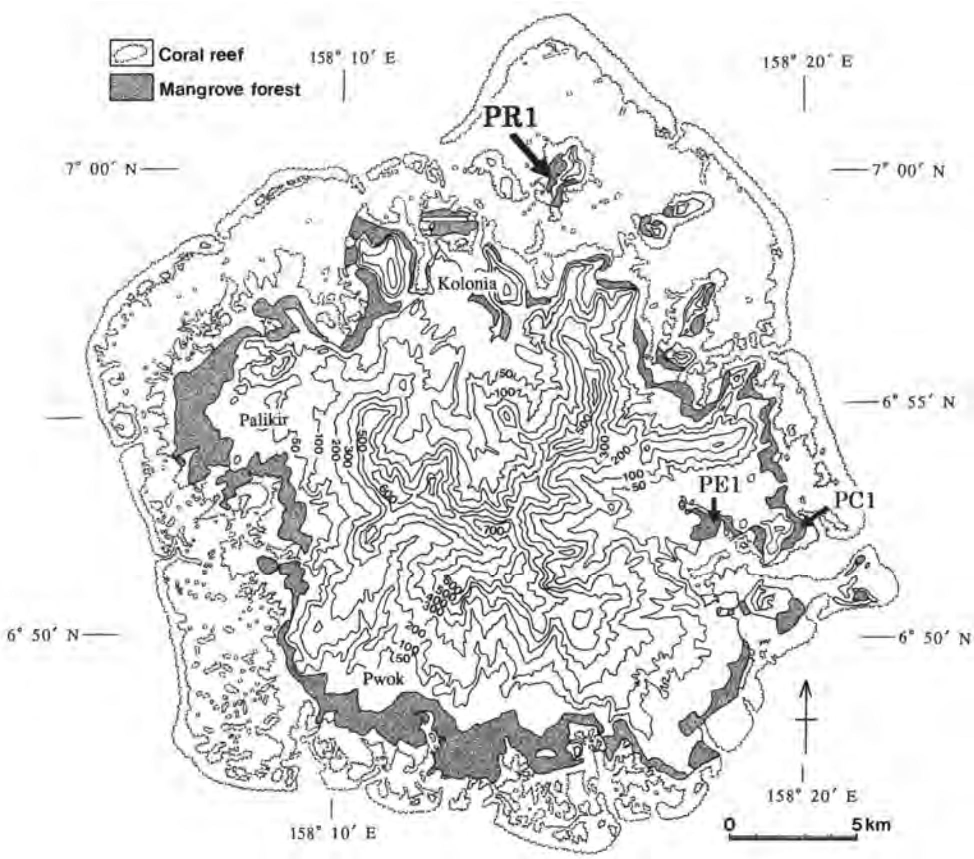

Fig.2 Landform of Pohnepi Island and distribution of mangrove habitats (after Fujimoto et al. 1995) and the location of the permanent plots

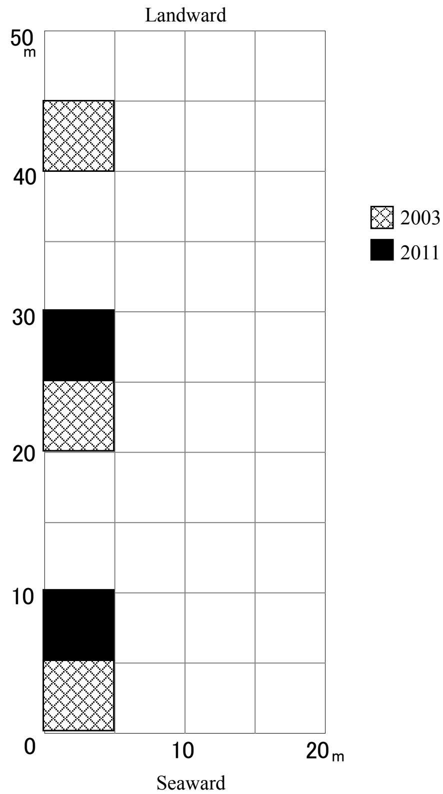

Fig.3 The quadrates where prop root biomass of *R. stylosa* were estimated in 2003 and 2011

7°04′ N and long. between 158°05′ and 23′ E (Fig. 1), has typical mangrove communities in the Pacific islands. The island consists of Tertiary volcanic rocks and has a total area of 35,500 ha. The annual average rainfall is 4,745 mm and there is no apparent dry season. The annual mean temperature is 27.1 ˚C with its annual range of less than 1 ˚C (Western Regional Climate Center 2012). The mean tidal range is 69 cm, and the maximum spring tidal range is 162 cm at Pohnpei Harbor (National Ocean Service 2011).

The island is surrounded by barrier reefs and the mangrove forests develop on the reef flats fringing the island though some of them are situated in the estuaries (Fig. 2). The former habitat is referred to as the coral reef type and the later as the estuary type. The area of mangrove forests reaches 5,290 ha. Mangrove forests in Pohnpei Island show clear zonation due to lack of significant human impacts.

Phytosociological description of mangrove forests in Pohnpei

The mangrove forests in Pohnpei are phytosociologically divided into three community types as follows: (Ⅰ) *R. stylosa* community, (Ⅱ) *Sonneratia alba* community, (Ⅲ) *R. apiculata - Bruguiera gymnorrhiza* community (Mochida et al. 2006). The first community is usually situated at the seaward edge of the coral reef type habitat which is 15 to 50 m in width and less than 10 m in height. It is marked by densely developed prop roots. This community is further classified into following three subcommunities:① typical subcommunity, ② *Enhalus acoroides* subcommunity and ③ *B. gymnorrhiza* subcommunity. The second community rarely appears along the seaward edge of the coral reef type habitat which is 10 to 20 m in width, and is characterized by the prostrate tree form and the high density of pneumatophores. The third community is further classified into the following three subcommunities: ① typical subcommunity, which sometimes appears behind the community Ⅰ, ② *S. alba* subcommunity, and ③*Xylocarpus granatum - Heritiera littoraris* subcommunity. Moreover, the subcommunity Ⅲ② is further categorized as: a) typical under-subcommunity usually appearing behind Ⅰ and Ⅱ communities, b) *X. granatum* under-subcommunity occupying the widest area of the mangrove forests in Pohnpei and generally appearing behind the under-subcommunity Ⅲ②a) in the coral reef type habitat and in the estuary type habitat, c) *Lumnitzera littorea* under-subcommunity appearing infrequently in the inland side of the mangrove forests. The subcommunity Ⅲ③ sometimes appears in the inland side also.

Methods

Survey for site environments

A rectangular permanent plot (PR1: 20 m wide and 50 m long) was established at the seaward edge of the mangrove forest dominated by *R. stylosa*, which corresponds to the I community by Mochida et al. (2006), in the west coast of Parempei Island located in the northern lagoon of Pohnpei Barrier Reef Island in September 2003 (Fig. 2). The 0 m line of the vertical scale in Fig. 3 nearly corresponds with the seaward edge of the mangrove forest.

The relative ground level was surveyed for every 10 m grid point of the permanent plot and up to 30 m seaward by measuring the water depth during a high tide, and adjusted to the elevation using the tide level at the time of the survey and the tide table at Pohnpei Harbor. The contour diagram was drawn with ArcGIS Spatial Analyst.

The thickness of the sediments was also examined for every 10 m grid point in the area of ground-level survey using a thin metallic rod. Soil water EC was sampled at 20 cm in depth at three points, 0 m, 25 m and 50 m from the seaward edge line, using Mizutolu soil water sampler (Daiki Rika Kogyo, Co., Ltd.) and was measured using portable EC meter (DKK-TOA, Co., Ltd.) in the field.

Estimation of standing biomass and productivity

The tree census was performed in Septembers of 2003, 2005 and 2011. All trees taller than 1.3 m in height were measured for stem diameter (D, cm) at 0.3 m above root collar for *Rhizophora* spp. with prop roots and 1.3 m above ground level for non-*Rhizophora* spp., respectively. Tree height (H, m) was estimated by using the following equation derived from the relationship between diameter and height:

$$1/H=0.97/D^{1.5}+1/10.22$$

The partial mass values of organs by each tree except for the prop roots of *R. stylosa*, i.e. stems (wS), branches (wB), leaves (wL), and fruits or reproductive organs (wF), were estimated by applying the allometry relationships described in Komiyama et al. (1988):

for *Rhizophora* species

$$wS=0.04036(D^2H)^{0.966}$$
$$wB=0.01046(D^2H)^{0.9103}$$
$$wL=0.06974(D^2H)^{0.5182}$$
$$wF=0.0003128(D^2H)^{1.0625}$$

for non-*Rhizophora* species

$$wS=0.02411(D^2H)^{0.9982}$$
$$wB=0.02563(D^2H)^{0.8534}$$
$$wL=0.008189(D^2H)^{0.8067}$$
$$wF=0.0002913(D^2H)^{0.7725}$$

Prop root biomass of *R. stylosa* (wR) was estimated by the following procedure: ① Five quadrates (5 m × 5 m) were set up at distances of 0-5 m, 5-10 m, 20-25 m, 25-30 m, 40-45 m from the seaward edge of the permanent plot (Fig. 3). The quadrates of 0-5m, 20-25m and 40-45m were measured in 2003 and the 5-10 m and 25-30 m were in 2011. We measured the length and diameter at the center of each prop root for all aboveground prop roots in each quadrate and calculated the root volume per unit area. On the measurement, we classified the prop roots into mature ones that are hard by sufficient lignification and soft ones that developed recently. ② Twelve samples of lignified prop roots and ten samples of soft ones were collected to estimate volume weight. Those dry weight (oven-drying at 105 ˚C for 24 hours) and volume were measured in the laboratory and then the specific gravity for each type of prop root was calculated. ③ Prop root biomass was computed by multiplying the root volume per unit area by the specific gravity for five quadrates. The prop root biomass data of 2003 was corrected to the value of 2011 using the growth rate of aboveground biomass for eight years calculated by the equations mentioned above.

Results

Species Distribution and peat thickness of R. stylosa habitat

The permanent plot was dominated by *R. stylosa* with a few *B. gymnorrhiza* in the landward part (Fig. 4), namely seaward and landward parts corresponded to Ⅰ① and Ⅰ③ subcommunities, respectively. The elevation in the plot ranged from -34 cm on the seaward edge to -13 cm on the landward edge. This means that *R.*

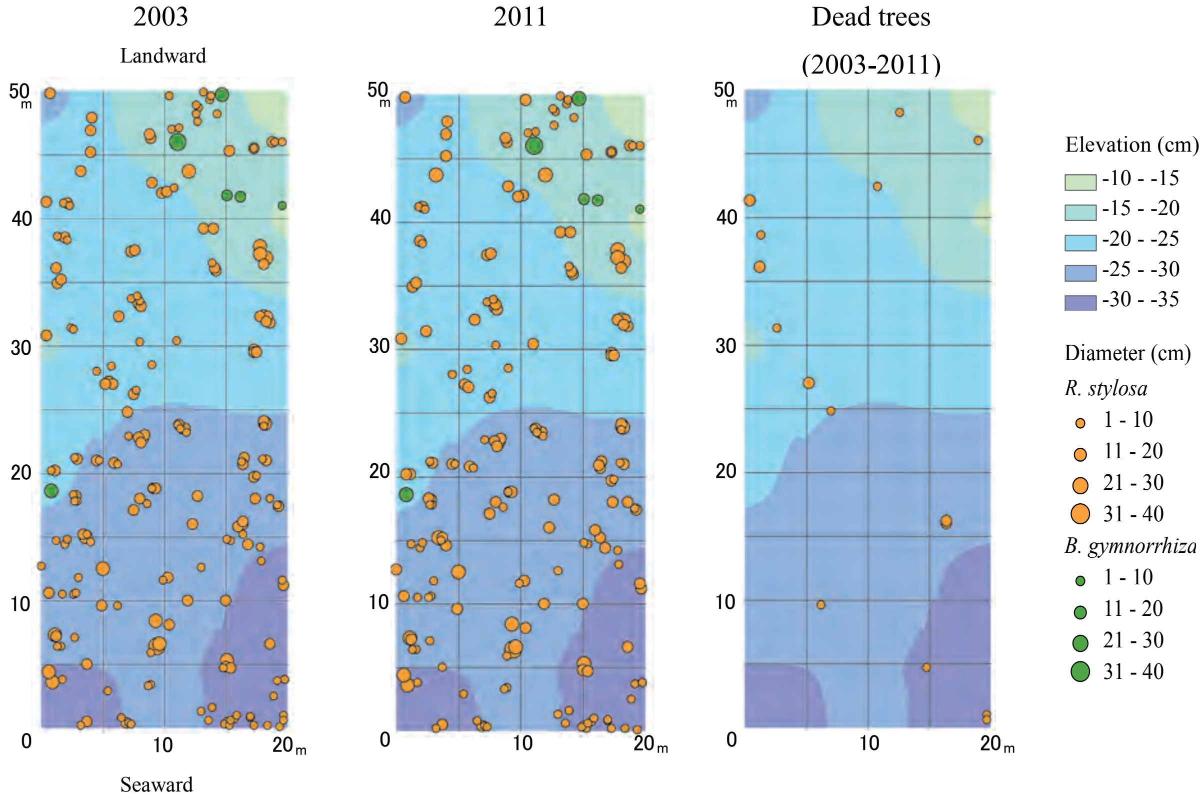

Fig.4 Ground elevation and distribution of each species trees in PR1

stylosa habitat occurs between slightly lower than the mean tide level and the mean low tide level. Thickness of the sediments in the plot ranged from 12 cm on the seaward edge to 61 cm on the landward edge, most of the sediments were mangrove peat except for the bottom portion of about 4 cm, which consists of coral sand.

Soil water EC

Soil water EC at 20 cm depth in the plot was 48.8 mS cm^{-1}, 50.8 mS cm^{-1} and 48.5 mS cm^{-1} for 0 m, 25 m and 50 m from seaward edge, respectively. There was no remarkable difference in three points. These values were almost equal to seawater EC and apparently higher than those of the Ⅲ② a) under-subcommunity in the coral reef type habitat and the Ⅲ② b) under-subcommunity in the estuary type habitat (Fujimoto et al. 1995).

Aboveground biomass and productivity

Tree density decreased from 2,120 trees ha^{-1} to 1,970 trees ha^{-1} between 2003 and 2011. There were 15 dead trees during the same period, all of which were blighted or downed wood of *R. stylosa* trees with a diameter below 16 cm. Frequency distribution of stem diameter in *R. stylosa* showed that 30 to 35 % of the trees occupied the diameter classes of both 5-10 cm and 10-15 cm (Fig. 5). The largest diameter was 34.5 cm for *R. stylosa*. Only one of *B. gymnorrhiza* tree showed a diameter below 15 cm and the largest size was 31.8 cm.

Values for the aboveground biomass of the plot in 2003, 2005 and 2011 were 228.7 t ha^{-1} (*R. stylosa*: 219.7 t ha^{-1}, *B. gymnorrhiza*: 9.0 t ha^{-1}), 235.6 t ha^{-1} (*R. stylosa*: 226.3 t ha^{-1}, *B. gymnorrhiza*: 9.2 t ha^{-1}) and 254.0 t ha^{-1} (*R. stylosa*: 244.5 t ha^{-1}, *B. gymnorrhiza*: 9.5 t ha^{-1}), respectively. Biomass of both species tended to have increased (Fig. 6). The increasing rate of aboveground biomass between 2003 and 2011was estimated at 3.2 t ha^{-1} yr^{-1}. On the other hand, necromass except for the prop roots was 4.3 t ha^{-1} and the occurrence rate of necromass was 0.5 t ha^{-1} yr^{-1} during the same period.

Table 1 shows the aboveground biomass of *R. stylosa* and *B. gymnorrhiza* by plant parts in 2003, 2005 and 2011. Prop root biomass in 2005 was estimated with

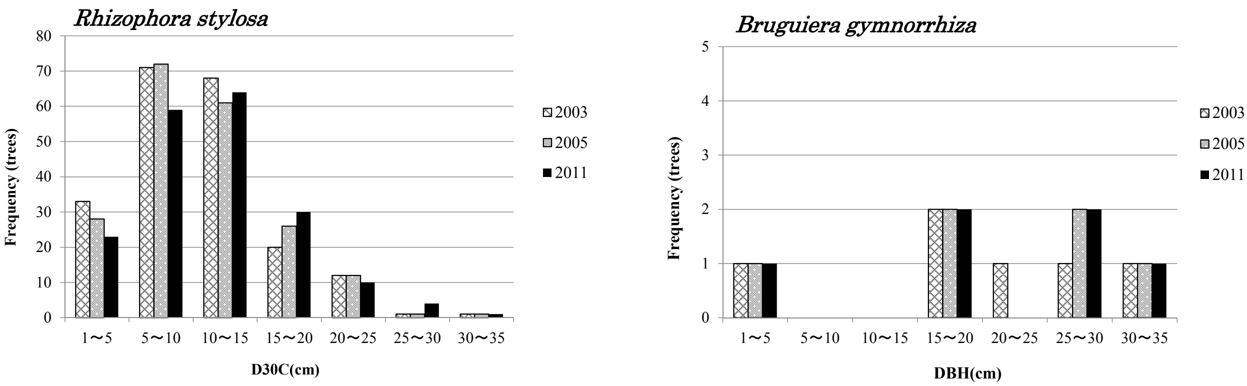

Fig.5 Frequency distribution of stem diameter in *R. stylosa* and *B. gymnorrhiza*
D30C: Diameter at 30 cm above root collar, DBH: Diameter at breast height

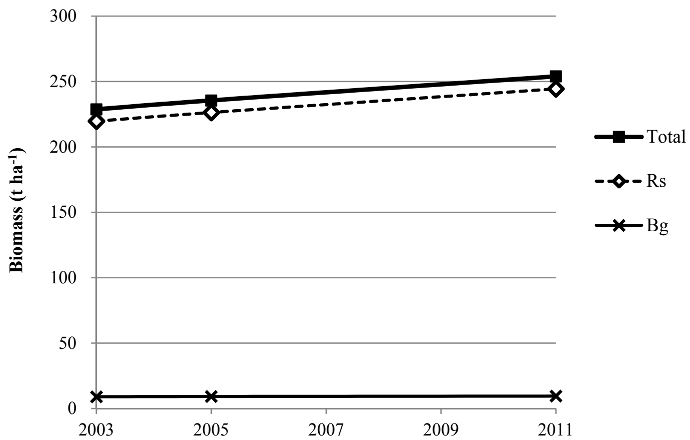

Fig.6 Dynamics of aboveground biomass between 2003 and 2011 at PR1
Rs: *Rhizophora stylosa*, Bg: *Bruguiera gymnorrhiza*

the annual increasing rate of the prop roots from 2003 to 2011 assuming that it increased at the same annual rate. The values of the dry mass of plant organs for each species expressed as wS, wB, wL, wF and wR for *R. stylosa* were calculated as 83.9 t ha^{-1} (34.3%), 14.2 t ha^{-1} (5.8%), 5.0 t ha^{-1} (2.0%), 0.2 t ha^{-1} (0.1%) and 141.3 t ha^{-1} (57.8%) for *R. stylosa* and 7.0 t ha^{-1} (73.3%), 2.1 t ha^{-1} (21.9%), 0.4 t ha^{-1} (4.7%), 0.01 t ha^{-1} (0.1%) for *B.gymnorrhiza*.

Table 2 indicates estimated values of the prop roots in 2003 and 2011. The values in the quadrates where measurements were not taken were estimated with the assumption of a constant annual increase of aboveground biomass except for the prop roots.

Standing carbon mass per unit area was found to be 102.9 t C ha^{-1}, 106.0 t C ha^{-1} and 114.3 t C ha^{-1} in 2003, 2005 and 2011, respectively, with the assumption of 45% carbon content in the dry mass. The annual increasing rate of carbon accumulation was 1.4 t C ha^{-1} yr^{-1} for the eight years.

Discussion

Prop root biomass ratio and environmental factors

Mangrove species are generally distributed in zones oriented in parallel to a shoreline in accordance with several environment factors and topography. Those zones are determined according to the growth range of mangrove species and are limited to the intertidal zone (e.g. Ishihara et al. 2004). The mangrove forest of this study located in the seaward fringe and it consisted mostly of *R. stylosa* with the component of 97% of tree density and 96% of aboveground biomass. The remainder was the minor *B. gymnorrhiza* trees in the inland portion of the plot.

The prop roots were spread around the forest floor

Table 1 Aboveground biomass by plant parts of *R. stylosa* and *B. gumnorrhiza* (unit: t ha^{-1})

Year	Species	wS	wB	wL	wF	wR	Subtotal	Total
2003	Rs	75.0	12.8	4.8	0.18	127.0	219.7	**228.7**
	Bg	6.6	2.0	0.4	0.011	0	9.0	
2005	Rs	77.6	13.2	4.8	0.19	130.5	226.3	**235.6**
	Bg	6.7	2.0	0.4	0.011	0	9.2	
2011	Rs	83.9	14.2	5.0	0.20	141.3	244.5	**254.0**
	Bg	7.0	2.1	0.4	0.012	0	9.5	

Rs: *Rhizophora stylosa*, Bg: *Bruguiera gymnorrhiza*

wS: stems, wB: branches, wL: leaves, wF: fruits and reproductive organs, wR: prop roots

Table 2 Estimated biomass of Prop roots for PR1 (unit: t ha^{-1})

	2003		2011	
Distance from seaward edge	Mature	Soft	Mature	Soft
0〜5 m	137.1	2.2	152.5**	2.4**
5〜10 m	118.5*	7.4*	131.8	8.2
20〜25 m	114.8	2.1	127.8**	2.3**
25〜30 m	128.0*	8.1*	142.4	9.0
40〜45 m	115.2	1.5	128.2**	1.7**
Mean	122.7	4.3	136.5	4.7
Total	127.0		141.3	

* The estimated values by 2011 assuming that prop roots increased as the same rate as other organs

** The estimated values by 2003 assuming that prop roots increased as the same rate as other organs

in this stand and biomass accounted for 58% of whole aboveground biomass. If prop root biomass was calculated with the allometric equations in Komiyama et al. (1988), the rate of prop root biomass (13.3%) was the clear underestimation. According to Ong et al. (2004), mixed forests of *R. apiculata* and *R. stylosa* have larger prop root biomass than pure forests of *R. apiculata* because *R. stylosa* generally has more extensive prop roots. The biomass equations in Komiyama et al. (1988) for *Rhizophora* spp. were mainly obtained by *R. apiculata*, so that the aboveground root biomass resulted as the underestimation. The production of the prop roots depends not only on what volume is needed for mechanical support, but also on different site-specific environmental factors e.g. micro-topography, salinity, flood frequency by the tides and other environmental stresses (Soares and Schaeffer-Novelli 2005). With increase in the salinity above an optimal level, relative growth rates of most aboveground parts decline and more carbon is allocated to roots than foliage (Ball 2002). It is supposed that geomorphologically unstable environment and high salinity affect the appreciably high productivity of prop roots in the seaward edge stand.

Comparing aboveground biomass and increasing rates with other major communities in Pohnpei

Two permanent plots, 1 ha (50 m × 200 m) each, have been set up at the main parts of mangrove forests in Pohnpei (Fig. 2), i.e. the estuary type (PE1) and the coral reef type (PC1), since 1994 (Fujimoto et al. 1995). Table 3 shows species composition, tree density, aboveground biomass, increasing rate of aboveground biomass and soil water EC in each plot. PE1 and PC1 were established in the Ⅲ② b) under-subcommunity

Table 3 Species composition, tree density, aboveground biomass, increasing rate of aboveground biomass and soil water EC in the permanent plots established in main mangrove communities in Pohnpei Island (The values of Soil water EC and others in PE1 and PC1 were quoted from Fujimoto et al. 1995 and Fujimoto et al. 2013, respectively.)

Plot No.	Species composition	Tree density (trees ha^{-1})	Aboveground biomass (t ha^{-1})	Growth rate of aboveground biomass (t ha^{-1} yr^{-1})	Soil water EC (mS cm^{-1})
PR1	**total**	**1970**	**254.0**	**3.2**	**48.5〜50.8**
	R. stylosa	1910(97%)	244.5(96%)		(M=49.6,
	B. gymnorrhiza	60(3%)	9.5(4%)		SD=0.9)
PE1	**total**	**473**	**743.6**	**6.1**	**26.5〜40.3**
	R. apiculata	285(60%)	238.2(32%)		(M=32.3,
	B. gymnorrhiza	110(23%)	121.9(16%)		SD=4.6)
	X. granatum	47(10%)	51.9(7%)		
	S. alba	31(7%)	331.7(45%)		
PC1	**total**	**1074**	**572.4**	**2.8**	**25.1〜47.6**
	R. apiculata	896(83%)	425.4(74%)		(M=36.6,
	B. gymnorrhiza	146(14%)	26.9(5%)		SD=7.8)
	S. alba	32(3%)	120.1(21%)		

M: the mean value of soil water EC, SD: the standard deviation

and the Ⅲ②a) under-subcommunity, respectively. Aboveground biomass for the present study site at PR1 was remarkably smaller than those plots and the growth rate was also lower than PE1 (Fujimoto et al. 2013). Soil water EC values ranged from 26.5 to 40.3 mS cm^{-1} in PE1 and from 25.1 to 47.6 mS cm^{-1} in PC1 (Fujimoto et al. 1995). On the other hand, it ranged from 48.5 to 50.8 mS cm^{-1} in PR1, which was almost same value of the seawater. The elevation of PR1, which was between -33.5 cm and -12.5 cm, was apparently lower than that of PE1 (between -10 cm and +15 cm except around a tidal creek in 1994) and PC1 (between +10 cm and +40 cm in 1994) (Fujimoto et al. 1995), which means that submergence frequency by tide is higher in PR1 than PE1 and PC1. The environmental stress with high salinity and submergence frequency which is related to geomorphological stability are possibly main factors for the relatively lower forest productivity and high density development of the prop roots in the *R. stylosa* forest.

The sea-level rise induced by global warming, which has been already observed to be +1.8 mm yr^{-1} between 1974 and 2004 and +16.9 mm yr^{-1} between 2002 and 2010 in Pohnpei, though the cause of the rapid rise in recent years is not clear (Bureau of Meteorology, Australian Government 2010), possibly affects the productivity and the habitat conditions. The continuous monitoring for the permanent plots is needed to detect the effects of sea-level rise to mangrove ecosystems.

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References

Ball, M.C. (2002): Interactive effects of salinity and irradiance on growth: Implications for mangrove forest structure along salinity gradients. Trees, 16, 126-139.

Bureau of Meteorology, Australian Government (2010): Pacific country report on sea level & climate: Their present state. Federated States of Micronesia. http://www.bom.gov.au/ntc/IDO60022/IDO60022.2010.pdf

Fujimoto, K., Tabuchi, R., Mori, T. and Murofushi, T. (1995): Site environments and stand structure of the mangrove forests on Pohnpei Island, Micronesia. JARQ, 29, 275-284.

Fujimoto, K., Tabuchi, R., Hirata, Y., Ono, K., Taniguchi, S. and Lihpai, S. (2013): Aboveground Dynamics and Productivity of Major Mangrove Communities on Pohnpei Island, Federated States of Micronesia. Global Environmental Research, 17, 207-214.

Ishihara, S., Fujimoto, K., Kawanishi, M., Watanabe, R. and Tanaka, S. (2004): Relationship between mangrove vegetation and micro-topography, and carbon storage of *Kandelia candel* (L.) Druce forests in Amami-ohshima Island, southwestern Japan. Japanese Journal of Forest Environment, 46, 9-19.

Komiyama, A., Ogino, K., Prawiroatmodjo, S., Toma, T. and Ogino, K. (1988): Primary productivety of mangrove forest. In Biological system of mangrove, A Report of East Indonesian Mangrove Expedition. ed. K. Ogino and M. Chihara, 97-117.

Komiyama, A., Ong, J. E. and Poungparn, S. (2008): Allometry, biomass, and productivity of mangrove forests:A review. Aquatic Botany, 89, 128-137.

Mochida, Y., Kikuchi, T., Fujimoto, K., Hirata, Y. and Tabuchi, R. (2006): A phytosociological study of the mangrove forests on Pohnpei Island, Micronesia. In Evaluation of the carbon fixation and organic matter decomposition functions in natural mangrove forests, Final Report of Study Supported by Grant-In-Aid for Scientific Research(A)(2)Japan Society for Promotion of Science.ed.R. Tabuchi, 4-10.

National Ocean Service (2011): Tide Tables 2012 – Central and Western Pacific Ocean and Indian Ocean. Table 1 – Daily prediction for reference stations. 208-211.
http://tidesandcurrents.noaa.gov/tidetables/2012/pttt2012book.pdf

Ong, J. E., Gong, W. K. and Wong, C. H. (2004): Allometry and partitioning of the mangrove, *Rhizophora apiculata*. Forest Ecology and Management, 188, 395-408.

Poungparn, S., Komiyama, A., Patanaponpaipoon, P., Jintana, V., Sangtiean, T., Tanapermpool, P., Piriyayota, S., Maknual, C. and Kato, S. (2002): Site-independent allometric relationships for estimating above-ground weights of mangroves. TROPICS, 12, 147-158.

Soares, M. L. G. and Schaeffer-Novelli, Y. (2005): Above-ground biomass of mangrove species: I. Analysis of models. Estuarine, Coastal and Shelf Science, 65, 1-18.

Western Regional Climate Center (2012): Pohnpei WSO, Pacific Ocean. Period of record general climate summary: Temperature & precipitation. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?pi4751