1   Growth Pattern In Tropical Mangrove Tress Of Bunaken National Park, North Sulawesi, Indonesia

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7   **Abstract.** Seasonal growth patterns and growth rate variation in tropical mangroves of Bunaken National Park (BNP) were investigated.
8   Dendrometer bands were installed on trees from twelve different sites in tropical mangroves of Bunaken National Park (BNP) to
9   measure stem growth rates. Growth rates measured in trees at the twelve sites varied significantly from 0.83 ± 0.27 to 1.71 ± 0.31 mm
10   month^{-1}. Growth rates were higher on *Sonneratia alba* (1.65 ± 0.69 mm month^{-1}), low on *Rhizophora stylosa, Xylocarpus moluccensis,*
11   *Avicennia marina, Ceriops tagal* (0.82 ± 0.16, 0.82 ± 0.18, 0.85 ± 0.18, 0.88 ± 0.28 mm month^{-1}, respectively), and medium on
12   *Rhizophora apiculata, Bruguiera parviflora, Bruguiera gymnorrhiza, Rhizophora mucronata* (1.19 ± 0.16, 1.22 ± 0.69, 1.25 ± 0.49,
13   1.31 ± 0.22 mm month^{-1}, respectively). Statistically, growth rates were higher in trees with initial girths more than 50 cm compared to
14   trees with initial girth less than 50 cm on *B. gymnorrhiza, C. tagal* and *R. mucronata,* but these were slower for *R. apiculata* and *S. alba*.
15   Growth rates varied among different site conditions, and the effect of soil water salinity on these was significant at higher intertidal sites.
16   Growth rates exhibited seasonal patterns, and these were correlated positively with rainfall and negatively with temperature. The effect
17   of the 2015-2016 El Nino was significant on reduced growth rates.

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19   **Keywords:** dendrometer, El Nino, growth rate, tropical mangrove

20   **INTRODUCTION**

21   Mangrove is a relatively small group of higher plants which have been peculiarly successful in colonising tropical and
22   sub-tropical intertidal habitats at the interface between land and sea (Clough 1979; Duke 1992; Kathiresan and Bingham
23   2001; Maxwell 2015). Mangroves, which are tolerant to salt and brackish waters (Spalding et al. 1997), have developed
24   complex morphological, anatomical, physiological, and molecular adaptations allowing survival and success in their high-
25   stress habitat (Srikanth et al. 2015). Despite of all the ecological services and economic benefits associated with mangrove
26   ecosystems, about 2.1% (2,834 km^2) of the existing worldwide mangrove area was estimated to be lost each year during
27   the second half of the 20th century (Valiela et al. 2001) and a total loss of 1.97% (1,646 km^2) from 2000 to 2012 (Hamilton
28   and Casey 2016).
29   Mangroves in many tropical locales exhibit seasonal diameter growth patterns, often as a consequence of distinctive
30   wet and dry seasons, and their seasonal patterns of growth are often related to rainfall, temperature, and relative moisture
31   regimes (Krauss et al. 2006). Mangrove trees of the same species may show different growth rates due to specific
32   environmental factors such as nutrients, salinity or inundation frequency of any localities (Suarez et al. 1998). According
33   to Menezes et al. (2003), abiotic factors may influence the individual growth rates, but their effect on the forest structure is
34   modified by biotic factors, such as neighbourhood competition.
35   As in many tropical tree species, annual growth rings are commonly said to be absent in mangroves (Gill 1971;
36   Tomlinson 1986), although these are claimed to be present in *Rhizophora mucronata* from the Kenyan coast (Verheyden et
37   al. 2004). It is proposed by Roberts et al. (2011) that the use of growth ring for age and growth rate determinations should
38   be evaluated on a case by case basis. In the absence of annual growth rings, dendrochoronological technique may not be
39   applied, and that in this case, dendrometer band to measure increments in circumference growth offers an alternative to
40   document fine-scale growth increments (Krauss et al. 2006). In practice, the growth rates of mangrove species may be a
41   useful indicator of site conditions resulting from change (Krause et al. 2006), key data of demographic processes to
42   investigate the development of mangrove forests (Menezes et al. 2003), necessary for the establishment of sustainable
43   silvicultural practices (Devoe and Cole 1998), important to generate a population model to determine cutting limits for
44   harvesting of the mangrove trees (Rajkaran and Adams 2008), and a fundamental measurement to understand tree biology
45   and physiology (Nasim et al. 2013).
46   The mangrove forests of Bunaken National Park (BNP) are among the most distinctive and unusual in Southeast Asia,
47   because of the species that the forests contain and the ecological processes that are now taking place (Davie et al. 1996;
48   Djamaluddin 2004). It is believed that the interplay between geophysical, geomorphic and biological factors has supported
49   the mangrove distribution and diversity in the intertidal environments of the Park. Last study reported that there were at
50   least 27 plant species distributed over ten sub-habitat types (Djamaluddin 2018). A common dieback phenomenon
51   associated with big trees of several species within the Park is also an important factor. While we do not know the lifespan
52   of mangrove trees, this dieback is presumed to relate to old age. Long lifespan of mangroves in this area may be supported
53   by their stable physical intertidal environments and the absence of catastrophic events (Djamaluddin 2004).
54   In this study, the growth dynamic of nine common encountered species in BNP was investigated. This study was
55   designed to examine growth rates of trees growing at different conditions of intertidal environment over a period of 59
56   months, including the period of the 2015-2016 El Nino. This allowed for comparison of growth rates by sites with
57   different conditions of tidal inundation and soil water salinity, by species from the same climatic zone and between the

| 58 | same trees species of large sizes and small sizes. In addition, seasonal pattern of growth rates was investigated using data
| 59 | of stem growth rates over several continuous wet and dry seasons, and growth dynamic in relation to rainfall and
| 60 | temperature was analysed. This study was conducted to test the hypothesis that growth rates are influenced by conditions
| 61 | of intertidal environments, and that distinct wet and dry seasons may have a consequence on seasonal pattern of growth
| 62 | rates.

MATERIALS AND METHODS

Description of climate

The rainfall in the study area is strongly affected by the wind systems (Djamaluddin 2004). The north-westerly winds blow over the South China Sea and bring moisture during September and April. In November, these winds arrive in the North Sulawesi via the Sulawesi Sea and to the west coast of South Sulawesi in late of November or early of December. Dry south-easterly winds blow from the wintery Australian land mass towards Eastern Sulawesi. These dry winds cause a short dry season in Manado from August to October. Based on data released by Manado Meteorology and Geo-physic Office, the total annual rainfall ranges from 2,501 to 3,000 mm. During 1973 to 2016, the annual temperature of North Sulawesi varies little between 25.5 ºC and 27.0 ºC. The minimum annual mean temperature of 25.5 ºC is recorded in 1984 and the maximum of 27.0 ºC in 2015.

Data collection and analysis

Four canopy trees were selected from each of the twelve different sites to measure stem growth rate in the form of girth increment. These sites represented conditions at high intertidal environment including Site 1 (highly accreting inland fringe habitat; 01°22'00.50" N, 124°33'18.84" E), Site 2 (less steep and eroding landward habitat; 01°22'01.53" N, 124°33'16.09" E), Site 3 (less steep landward habitat; 01°22'05.50" N, 124°33'16.37" E), Site 11 (freshwater influenced habitat; 01°19'43.85" N, 124°31'14.14" E); low intertidal environment or seaward fringe habitat including Site 4 (01°22'24.37" N, 124°33'10.31" E), Site 5 (01°22'20.01" N, 124°33'04.72" E), and Site 7 (01°22'13.57" N, 124°32'58.41" E); middle intertidal environment including Site 10 (01°21'38.79" N, 124°32'40.84" E); tidal stream edge or river levee habitat including Site 6 (01°22'21.08" N, 124°33'09.00" E) and Site 8 (01°22'07.20" N, 124°33'04.20" E); and transgressed bedrock coast habitat including Site 12 (01°19'43.17" N, 124°31'45.00" E).

The growth rates of selected trees were measured every two months during July 1999 to June 2001 and March 2014 to December 2016, using fixed dendrometer bands made with DYMO labelling tape produced by DYMO Esselte Pendaflex Corporation. These bands were attached around tree trunks using a spring and expand as the tree grows. The extent of girth expansion was measured on the tape using a micrometre.

Before the setting up of dendrometer in August 1999, data of structural attributes, soil water salinity, and tidal inundation were measured during July 1999. Structural attributes in the form of species composition and height of tree canopy were assessed to descript structural attributes of ecological mangrove communities at sample sites. Field determination of the flora were confirmed by a range of systematic reviews (e.g. Ding Hou 1958; Tomlinson 1986; Noor et al. 2006). The canopy height was measured directly by means of a long fixed stick for trees with height up to 5 m and, for taller trees, it was indirectly measured by using of a clinometer (SUNTO MC 1 Type). Surface soil sample were taken at 0 to 300 mm depth at five random points in every location, and soil water salinity was measured using a Hand-Held Refractometer (Atago Master-S/Mill) of water samples of a known volume eluted through sediment samples. Level of tidal inundation was observed at all sites during early neap-tide, full moon-tide and late neap-tide. A pole gage was used to measure level of tidal inundation. Data of rainfall and temperature were based on the reports from Manado Meteorology and Geo-Physic Office.

In analysing the differences in stem growth rate by species and sites, the one-way analysis of variance (ANOVA) was applied. Regression Analysis was used to analyse the effect of rainfall and temperature on stem growth rate. The twelve sites that were regarded as having different environmental conditions and community attributes can be seen in Figure. 1 and these are summarised in Table. 1.

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https://www.researchgate.net/publication/301646583_Ecological_and_socio-economic_functions_across_tropical_land_use_systems_after_rainforest_conversion

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107 Figure 1. Locations of the twelve sites sampled at Southern Section of Bunaken National Park. Inserted Figure. 1A is dendrometer on
108 trees number 3 at Site 1, inserted Figure. 1B is map of Indonesia with red dot indicating study location on Sulawesi Island and equator
109 line across the Country

110
111 Table 1. Description of the twelve sites sampled where four canopy trees in each site were selected for the measurement of stem growth
112 rate: SD (Standard Deviation) of five random soil samples, tidal inundation frequency represented number of day month^{-1} a site being
113 inundated by seawater

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Site	Species of Tree Sampled	Initial Tree Girths (cm)	Average Height of Canopy (m)	Soil Water Salinity (average ± SD, µg L^{-1})	Tidal Inundation Frequency (%)
Site 1	A. marina	61.5 – 98.4	17	14.3 ± 0.47	< 13
Site 2	C. tagal	17.0 – 22.8	2.5	19.5 ± 0.00	13 – 22
Site 3	R. apiculata	16.0 & 18.5	4	19.0 ± 0.00	22 – 30
	C. tagal	21.4 & 30.0			
Site 4	R. apiculata	39.0 & 41.5	6	14.0 ± 0.00	45 – 50
	R. mucronata	22.5			
	B. gymnorrhiza	29.0			
Site 5	B. gymnorrhiza	91.5 &	8	14.0 ± 0.02	45 – 50
	R. mucronata	104.5			
		30.0 & 40.0			
Site 6	A. marina	93.5	7	18.0 ± 0.82	30 – 45
	B. gymnorrhiza	71.0			
	X. moluccensis	55.0			
	R. apiculata	15.0			
Site 7	R. mucronata	34.0	8	18.0 ± 0.00	45 – 50
	S. alba	47.5			
	R. apiculata	47.5			
Site 8	A. marina	118.0	8	17.5 ± 0.21	30 – 45
	B. parviflora	38.5			
	R. apiculata	53.5 &59.5			
Site 9	R. stylosa	72.5 & 88.0	22	14.0 ± 0.00	45 – 50
	S. alba	64.0 & 118.5			
Site 10	R. apiculata	102.0 & 105.0	22	19.7 ± 1.25	30 – 45
	B. gymnorrhiza	90.0 & 96.0			
Site 11	C. tagal	50.0 – 102.0	12	6.5 ± 0.50	13 – 22
Site 12	S. alba	129.5	27	13.3 ± 0.47	> 90
	R. apiculata	79.0			

R. mucronata	104.0
A. marina	99.0

RESULTS AND DISCUSSION

Variation between sites

Figure 2 shows the stem growth rates at different sites. The result from the ANOVA statistical test suggested that the differences in stem growth rate were significant between the twelve sites (F (11,324) = 5.848, p-value = 0.00, < 0.05). The highest growth rates were found in trees at Site 5 and 7 where increments were 1.53 ± 0.54 and 1.71 ± 0.31 mm month[-1] respectively. At Site 1 the average stem growth rates varied in the range of 1.01 ± 0.30 mm month[-1]. This range was slightly lower comparing to that on sample trees at Site 4 of 1.05 ± 0.15 mm month[-1], Site 6 of 1.07 ± 0.19 mm month[-1], and Site 11 of 1.05 ± 0.42 mm month[-1]. Slightly lower stem growth rates were measured on trees at Site 3, 12, 2, and Site 8 of 0.83 ± 0.27, 0.84 ± 0.25, 0.90 ± 0.39, 0.92 ± 0.31 mm month[-1] respectively. Trees at Site 9 and 10 had average stem growth rates which were comparable, measured at 1.24 ± 0.24 and 1.20 ± 0.53 mm month[-1] respectively.
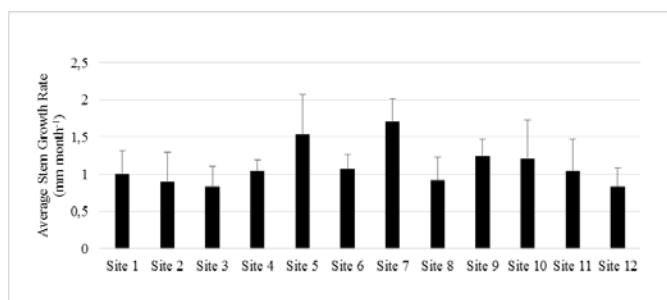

Figure 2. Average stem growth rates of tagged trees at various sites over 59 months. Error bars are standard deviations representing variability over 59 months

Differing conditions at the study sites resulted in different growth rates of mangrove species. Results from this study indicate that higher growth rates were measured at Site 5 and 7 (low intertidal environment) where soil water salinity was at intermediate level (14.0 ± 0.02 µg L^{-1} and 18.0 ± 0.00 µg L^{-1}, respectively), and a relatively lower growth rate was recorded for trees growing at Site 2 and 3 (high intertidal environment) where soil water salinity was relatively higher (19.5 ± 0.00 µg L^{-1} and 19.0 ± 0.00 µg L^{-1}, respectively). The effect of soil water salinity on growth rate might be inconsistent considering a relative lower growth rate at Site 8 and 12 where soil water salinity was at intermediate level (17.5 ± 0.21 and 13.3 ± 0.47 µg L^{-1}). This inconsistency was probably due to the existence of micro-topography in form of the river levee at Site 8 and transgressed bedrock coast at Site 12. These micro-topography variations according to Thom (1982) can cause varying physiological responses in different species and there may be more or less favourable plant growth in a specific habitat due to the response of species to stress conditions.

Although soil water salinity was relatively higher (19.7 ± 1.25 µg L^{-1}) at Site 10, growth rates of trees at this site were measured at medium growth rate. This rate of growth was probably affected by tidal inundation frequency of this site that was measured at 30 to 45% compared to 13 to 30% at Site 2 and 3. How trees of *B. gymnorrhiza* and *R. apiculata* respond to specific conditions at Site 10 needs further investigation. The effect of salinity on mangrove growth has been reported by various studies (e.g. Robert et al. 2009; Menesez et al. 2003; Nasim et al. 2013; Noor et al. 2015). In Pakistan, for example, Nasim et al. (2013) reported that the maximum growth rate of *A. marina* was presumably due to low salinity and the minimum growth rate was related to higher salinity. Similar pattern was reported by Menesez et al. (2003) in the mangroves from Braganca Peninsula, North Brazil. In mangrove forests, conditions of high salinity can cause osmotic stress and reduce the availability of water, resulting in stomatal closure and reduced supply of carbon dioxide (Li et al. 2008). Furthermore, membrane disorganisation and disturbance of nutrient balance may be induced by salt stress (Hasegawa et al. 2000).

Variation between species

Figure 3 shows the stem growth rate for nine species. The result from the ANOVA statistical test indicated that average stem growth rate was significantly different between species (F (8,243) = 7.063, p-value = 0.00, < 0.05). A relatively highest growth was measured on *S. alba* (1.65 ± 0.69 mm month^{-1}) and a relatively lowest growth on *R. stylosa, X. moluccensis, A. marina, C. tagal*, measured at 0.82 ± 0.16, 0.82 ± 0.18, 0.85 ± 0.18, 0.88 ± 0.28 mm month^{-1} respectively. A relatively medium growth rate was measured on *R. apiculata, B. parviflora, B. gymnorrhiza, R. mucronata*, measured at 1.19 ± 0.16, 1.22 ± 0.69, 1.25 ± 0.49, 1.31 ± 0.22 mm month^{-1}, respectively. When the growth rates were expressed as a percentage of the initial girth of each tagged tree, there was apparently higher stem growth rates on tagged trees of *B. gymnorrhiza, C. tagal* and *R. mucronata* with an initial girth of more than 50 cm compared to trees with an initial girth of less than 50 cm. Conversely, there was a relatively slower growth rate on tagged trees of *R. apiculata* and *S. alba* with an original girth of more than 50 cm compared to trees with an initial girth of less than 50 cm. For other species, comparison of growth rates between trees with an initial girth more than 50 cm and less than 50 cm was not evaluated because the absence of comparable data.
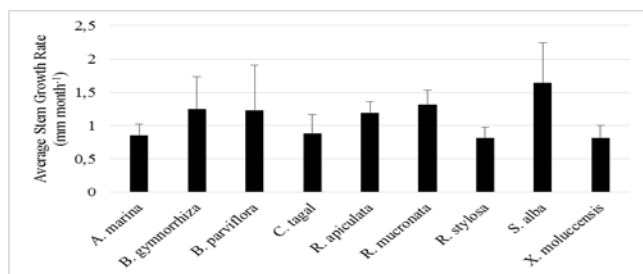
Figure 3. Average stem growth rate of nine species over 59 months; error bars (Standard Deviations) represented variability over 59 months

Table 2. Average stem growth rate (girth increment and as percentage of initial girth measured for nine species over 59 months); error bars (Standard Deviations) represented variability over 59 months, n represented number of tagged tree

Species	Stem Growth Rate as Percent Initial Girth in mm/month (mean ± SD)	
	< 50 cm	> 50 cm
A. marina	-	0.85 ± 0.58 (n = 7)
B. gymnorrhiza	0.83 ± 0.55 (n = 1)	1.33 ± 1.05 (n = 5)
B. parviflora	1.22 ± 0.81 (n = 1)	-
C. tagal	0.80 ± 0.59 (n = 8)	1.21 ± 0.76 (n = 2)
R. apiculata	1.37 ± 0.59 (n = 6)	0.96 ± 0.58 (n = 5)
R. mucronata	0.47 ± 0.56 (n = 4)	0.69 ± 0.59 (n = 1)
R. stylosa	-	0.85 ± 0.48 (n = 2)
S. alba	1.73 ± 0.89 (n = 2)	1.60 ± 0.92 (n = 3)
X. moluccensis	-	0.82 ± 0.41 (n = 1)

Results from this study confirmed that the nine mangrove species had different growth rate, and the growth rate recorded in this study is different compared to those conducted elsewhere. For example, the annual diameter increment of *R. apiculata* was 0.32 cm year^{-1} in mature mangrove forests in Malaysia (Putz and Chan 1986) and 0.25 cm year^{-1} in the mangrove forests in Micronesia (Devoe and Cole 1998) which were lower than the average growth rate by this species in this study (0.45 cm/year). For *B. gymnorrhiza,* the annual growth increments were reported 0.35 cm year^{-1} in Micronesia which were relatively lower compared to the growth rate of this species in this study (0.48 cm year^{-1}). The annual diameter increments of *S. alba* were reported 0.49 cm year^{-1} in the mangrove forests in Micronesia (Devoe and Cole 1998) which were relatively lower compared to the growth rates of these species measured in this study (0.60 cm year^{-1}). Differences in growth rate of similar species from different places explained the important role of local environment and climatic condition to growth of mangrove species.

In this study, large trees of *B. gymnorrhiza, C. tagal, R. mucronata* grew faster than small trees. The case for trees of *B. gymnorrhiza* and *R. mucronata* might explain that trees of these species remained at vigorous growth. Meanwhile, the case for trees of *C. tagal* might be different. Small trees of this species were found dominant at Site 2 and 3 where salinity is usually higher, and that trees are growing stunted at this condition. Sample of large trees of this species were found at Site 11 where soil water salinity was lower. Thus, in the case of *C. tagal*, differences in growth rate between small and large trees were due to primarily soil water salinity.

Seasonal variation

Figure 4 shows average stem growth rates of 48 tagged trees selected from 12 different sites. This figure shows that average stem growth rate started to increase in August or October over a year. This trend reached a maximum value in February at different levels with the highest level of 2.24 mm month^{-1} in February 2001 and the lowest level of 1.33 mm month^{-1} in February 2016. From February, stem growth rate decreased and reached minimum value around August and October at different levels ranging from 0.53 mm month^{-1} in August 2015 to 0.74 mm month^{-1} in August 2014. Between April 2015 and February 2016 there was abnormality in stem growth rate. During this period rates of average stem growth rates were apparently low.
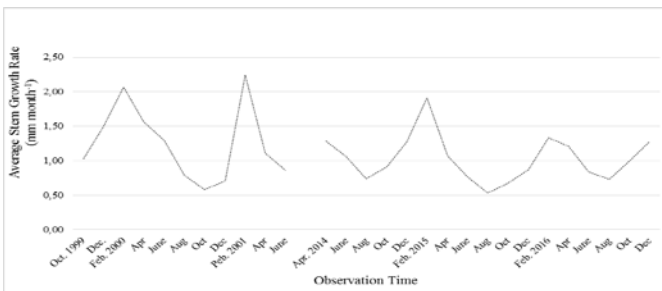

Figure 4. Temporal average stem growth rate over 59 months

A seasonal pattern in stem growth rates is very clear from data in Figure 4 and this is supported by the result from regression analyses, multiple and simple analyses. When two variables of rainfall and temperature were involved in the analysis the result confirmed that the regression model was significant (p-value < 0.05). Similar result was confirmed from simple regression with single variable of rainfall and temperature (p-value < 0.05). Figure 5 shows relationship between rainfall and stem growth rate. It is clear from this figure that rainfall positively correlated with stem growth. On the contrary, temperature negatively correlated with stem growth as shown in Figure 6.
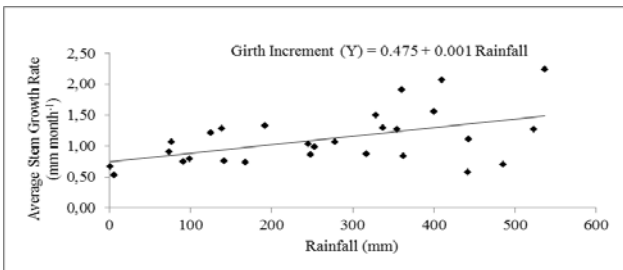
Figure 5. Relation between rainfall and stem growth rate
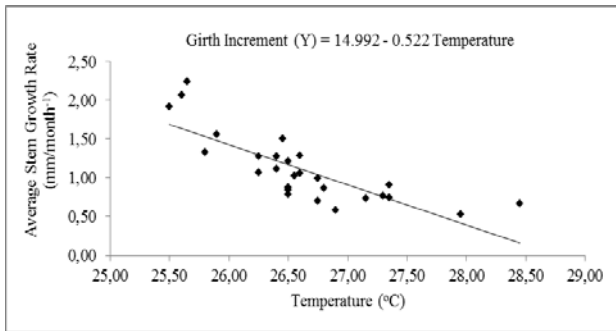
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Figure 6. Relation between rainfall and stem growth rate

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Previous studies indicated that growth rate in mangroves is seasonal (e.g. Jintana et al. 1985; Day 1990; Krauss et al. 2006). Field measurements indicated that growth rate is seasonal in study sites and this correlates positively with rainfall and negatively with temperature. Duke et al. (1981) also found that the growth of the tropical mangrove trees *Diospyros* was related to rainfall, producing 0.272 mm^2 growth increment per millimetre rain. This positive correlation between rainfall and growth rate was reported for *Bruguiera* and *Rhizophora* species in Thailand (Jintana et al. 1985) and for the mangroves in Laguna de Terminos, Mexico (Day 1990).

The effect of rainfall and temperature on intertidal environment where mangroves grew may be related to two factors; water availability and soil water salinity. Between these two factors, soil water salinity is assigned as the major seasonal variable causing wood anatomical changes and hence growth rings (Robert et al. 2009). In addition, Robert et al. (2011) in their study of the mangrove forest of Gazi Bay at the Kenyan coast confirmed that climatic conditions that result in a range of soil water salinity experienced over the year were a prerequisite for the formation of growth rings. The low growth rate that was recorded between April 2015 and February 2016 corresponds with a dry season. The effect of the 2015/2016 El Nino-Southern Oscillation (ENSO) resulted in reduced rainfall in the region with only 450.3 mm rainfall in total for eight months from March to October 2015. The most severe drought condition lasted for four months from July to October 2015 with only 13 mm rainfall in total.

Although, the volume of rainfall returned to normal by November 2015 measured at 337 mm month^{-1}, the effect of the drought on low growth rate continued until February 2016. Drexler and Ewel (2001) studied the effect of the 1997-1998 ENSO related drought on hydrology and salinity in a Micronesian Wetland Complex. They found that mean salinity during low tide was approximately twice as high during the drought, and short-term climate perturbations such as ENSO can disrupt important coastal processes. Over repeated drought cycles, such perturbations have the potential to affect the structure and function of mangrove forests. The effect of drought on mangroves can be related to the decrease of carbon assimilation rate (Sobrado 1999), decrease of net photosynthetic rate and low water use efficiency (Sobrado 2006).

In conclusion, stem growth rates in mangrove trees growing at different habitats varied considerably, and the factor of soil water salinity seemed to be the major cause of this variation at high intertidal environment. The higher stem growth rate was measured on mangrove trees growing at low intertidal environment with low to medium soil water salinity and higher tidal inundation frequency. Soil water salinity and growth rates relationship may not be significant in the existence of micro-topography such as river levee and transgressed bedrock coast, and in the case at the middle intertidal environment where trees of *B. gymnorrhiza* and *R. apiculata* were dominant in the canopy. The stem growth rates were significantly different between the ten species observed with a relatively higher growth rate on *S. alba*, a medium growth rate on *R. apiculata, B. parviflora, B. gymnorrhiza, R. mucronata,* and a low growth rate on *R. stylosa, X. molucensis, A. marina, C. tagal.* Growth rates on trees with an original girth of more than 50 cm were higher on *B. gymnorrhiza, C. tagal* and *R.* mucronata, but these were higher on trees with an original girth of less than 50 cm on *R. apiculata* and *S. alba.* Growth rate patterns in observed mangroves were seasonal, and this pattern correlated positively to rainfall and negatively to temperature. The effect of the 2015-2016 El Nino on reduced growth rates was significant on mangroves in the study site.

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