

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

Abstract. Seasonal growth patterns and growth rate variation in tropical mangroves of Bunaken National Park (BNP) were investigated. Dendrometer bands were installed on trees from twelve different sites in tropical mangroves of Bunaken National Park (BNP) to 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 month⁻¹. Growth rates were higher on *Sonneratia alba* (1.65 ± 0.69 mm month⁻¹), low on *Rhizophora stylosa*, *Xylocarpus moluccensis*, *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 *Rhizophora apiculata*, *Bruguiera parviflora*, *Bruguiera gymnorrhiza*, *Rhizophora mucronata* (1.19 ± 0.16 , 1.22 ± 0.69 , 1.25 ± 0.49 , 1.31 ± 0.22 mm month⁻¹, respectively). Statistically, growth rates were higher in trees with initial girths more than 50 cm compared to 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*. Growth rates varied among different site conditions, and the effect of soil water salinity on these was significant at higher intertidal sites. Growth rates exhibited seasonal patterns, and these were correlated positively with rainfall and negatively with temperature. The effect of the 2015-2016 El Nino was significant on reduced growth rates.

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

Commented [KT1]: have not been described in detail and concisely how the method of analysis

INTRODUCTION

Mangrove is a relatively small group of higher plants which have been peculiarly successful in colonising tropical and sub-tropical intertidal habitats at the interface between land and sea (Clough 1979; Duke 1992; Kathiresan and Bingham 2001; Maxwell 2015). Mangroves, which are tolerant to salt and brackish waters (Spalding et al. 1997), have developed complex morphological, anatomical, physiological, and molecular adaptations allowing survival and success in their high-stress habitat (Srikanth et al. 2015). Despite of all the ecological services and economic benefits associated with mangrove ecosystems, about 2.1% (2,834 km²) of the existing worldwide mangrove area was estimated to be lost each year during the second half of the 20th century (Valiela et al. 2001) and a total loss of 1.97% (1,646 km²) from 2000 to 2012 (Hamilton and Casey 2016).

Mangroves in many tropical locales exhibit seasonal diameter growth patterns, often as a consequence of distinctive wet and dry seasons, and their seasonal patterns of growth are often related to rainfall, temperature, and relative moisture regimes (Krauss et al. 2006). Mangrove trees of the same species may show different growth rates due to specific environmental factors such as nutrients, salinity or inundation frequency of any localities (Suarez et al. 1998). According to Menezes et al. (2003), abiotic factors may influence the individual growth rates, but their effect on the forest structure is modified by biotic factors, such as neighbourhood competition.

As in many tropical tree species, annual growth rings are commonly said to be absent in mangroves (Gill 1971; Tomlinson 1986), although these are claimed to be present in *Rhizophora mucronata* from the Kenyan coast (Verheyden et al. 2004). It is proposed by Roberts et al. (2011) that the use of growth ring for age and growth rate determinations should be evaluated on a case by case basis. In the absence of annual growth rings, dendrochronological technique may not be applied, and that in this case, dendrometer band to measure increments in circumference growth offers an alternative to document fine-scale growth increments (Krauss et al. 2006). In practice, the growth rates of mangrove species may be a useful indicator of site conditions resulting from change (Krause et al. 2006), key data of demographic processes to investigate the development of mangrove forests (Menezes et al. 2003), necessary for the establishment of sustainable silvicultural practices (Devoe and Cole 1998), important to generate a population model to determine cutting limits for harvesting of the mangrove trees (Rajkaran and Adams 2008), and a fundamental measurement to understand tree biology and physiology (Nasim et al. 2013).

The mangrove forests of Bunaken National Park (BNP) are among the most distinctive and unusual in Southeast Asia, because of the species that the forests contain and the ecological processes that are now taking place (Davie et al. 1996; Djamaluddin 2004). It is believed that the interplay between geophysical, geomorphic and biological factors has supported the mangrove distribution and diversity in the intertidal environments of the Park. Last study reported that there were at least 27 plant species distributed over ten sub-habitat types (Djamiluddin 2018). A common dieback phenomenon associated with big trees of several species within the Park is also an important factor. While we do not know the lifespan of mangrove trees, this dieback is presumed to relate to old age. Long lifespan of mangroves in this area may be supported by their stable physical intertidal environments and the absence of catastrophic events (Djamiluddin 2004).

In this study, the growth dynamic of nine common encountered species in BNP was investigated. This study was designed to examine growth rates of trees growing at different conditions of intertidal environment over a period of 59

57 months, including the period of the 2015-2016 El Nino. This allowed for comparison of growth rates by sites with
58 different conditions of tidal inundation and soil water salinity, by species from the same climatic zone and between the
59 same trees species of large sizes and small sizes. In addition, seasonal pattern of growth rates was investigated using data
60 of stem growth rates over several continuous wet and dry seasons, and growth dynamic in relation to rainfall and
61 temperature was analysed. This study was conducted to test the hypothesis that growth rates are influenced by conditions
62 of intertidal environments, and that distinct wet and dry seasons may have a consequence on seasonal pattern of growth
63 rates.

Commented [KT2]: were analyzed

64 MATERIALS AND METHODS

65 Description of climate

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

74 Data collection and analysis

75 Four canopy trees were selected from each of the twelve different sites to measure stem growth rate in the form of girth
76 increment. These sites represented conditions at high intertidal environment including Site 1 (highly accreting inland
77 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,
78 124°33'16.09" E), Site 3 (less steep landward habitat; 01°22'05.50" N, 124°33'16.37" E), Site 11 (freshwater influenced
79 habitat; 01°19'43.85" N, 124°31'14.14" E); low intertidal environment or seaward fringe habitat including Site 4
80 (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"
81 E); middle intertidal environment including Site 10 (01°21'38.79" N, 124°32'40.84" E); tidal stream edge or river levee
82 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
83 bedrock coast habitat including Site 12 (01°19'43.17" N, 124°31'45.00" E).

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

Commented [KT3]: labeling

88 Before the setting up of dendrometer in August 1999, data of structural attributes, soil water salinity, and tidal
89 inundation were measured during July 1999. Structural attributes in the form of species composition and height of tree
90 canopy were assessed to describe structural attributes of ecological mangrove communities at sample sites. Field
91 determination of the flora were confirmed by a range of systematic reviews (e.g. Ding Hou 1958; Tomlinson 1986; Noor et
92 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
93 taller trees, it was indirectly measured by using of a clinometer (SUNTO MC 1 Type). Surface soil sample were taken at 0
94 to 300 mm depth at five random points in every location, and soil water salinity was measured using a Hand-Held
95 Refractometer (Atago Master-S/Mill) of water samples of a known volume eluted through sediment samples. Level of tidal
96 inundation was observed at all sites during early neap-tide, full moon-tide and late neap-tide. A pole gage was used to
97 measure level of tidal inundation. Data of rainfall and temperature were based on the reports from Manado Meteorology
98 and Geo-Physic Office.

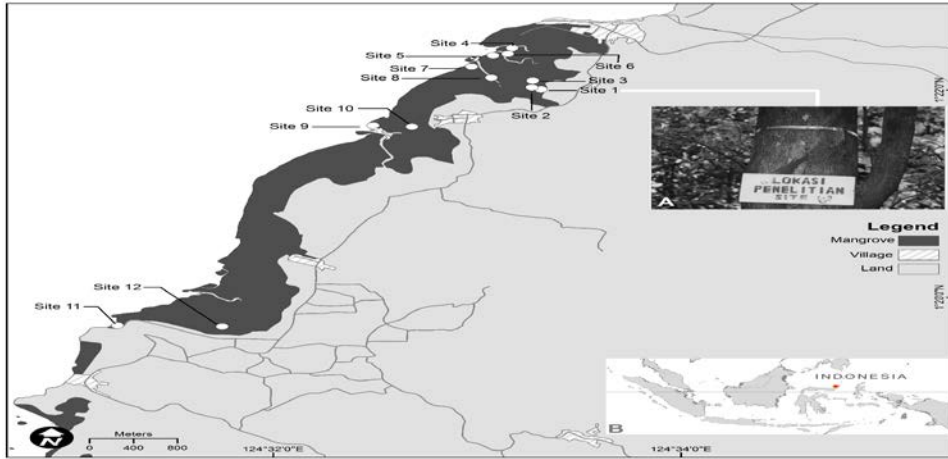
99 In analysing the differences in stem growth rate by species and sites, the one-way analysis of variance (ANOVA) was
100 applied. Regression Analysis was used to analyse the effect of rainfall and temperature on stem growth rate. The twelve
101 sites that were regarded as having different environmental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

Commented [KT4]: how many replications from each sites?

Commented [KT5]: replaced into simple linear regression

103
104

105



106

107

108

109

110

111

112

113

114

115

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

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

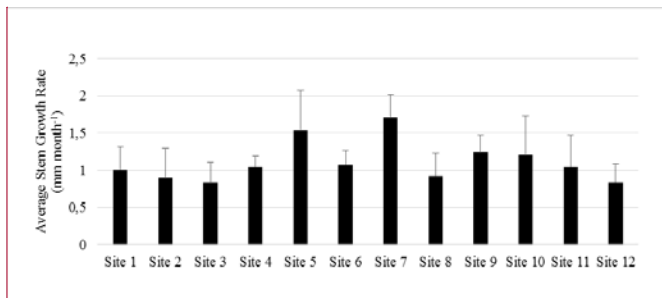
Site	Species of Tree Sampled	Initial Tree Girths (cm)	Average Height of Canopy (m)	Soil Water Salinity (average ± SD, µg L ⁻¹)	Tidal Inundation Frequency (%)
Site 1	<i>A. marina</i>	61.5 – 98.4	17	14.3 ± 0.47	< 13
Site 2	<i>C. tagal</i>	17.0 – 22.8	2.5	19.5 ± 0.00	13 – 22
Site 3	<i>R. apiculata</i>	16.0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

12	<i>R. apiculata</i>	79.0
	<i>R. mucronata</i>	104.0
	<i>A. marina</i>	99.0

117 RESULTS AND DISCUSSION

118 Variation between sites

119 Figure 2 shows the stem growth rates at different sites. The result from the ANOVA statistical test suggested that the
 120 differences in stem growth rate were significant between the twelve sites ($F(11,324) = 5.848, p\text{-value} = 0.00, < 0.05$). The
 121 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
 122 respectively. At Site 1 the average stem growth rates varied in the range of 1.01 ± 0.30 mm month⁻¹. This range was
 123 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,
 124 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
 125 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
 126 growth rates which were comparable, measured at 1.24 ± 0.24 and 1.20 ± 0.53 mm month⁻¹ respectively.



128 Figure 2. Average stem growth rates of tagged trees at various sites over 59 months. Error bars are standard deviations representing
 129 variability over 59 months
 130
 131
 132

133 Differing conditions at the study sites resulted in different growth rates of mangrove species. Results from this study
 134 indicate that higher growth rates were measured at Site 5 and 7 (low intertidal environment) where soil water salinity was
 135 at intermediate level ($14.0 \pm 0.02 \mu\text{g L}^{-1}$ and $18.0 \pm 0.00 \mu\text{g L}^{-1}$, respectively), and a relatively lower growth rate was
 136 recorded for trees growing at Site 2 and 3 (high intertidal environment) where soil water salinity was relatively higher
 137 ($19.5 \pm 0.00 \mu\text{g L}^{-1}$ and $19.0 \pm 0.00 \mu\text{g L}^{-1}$, respectively). The effect of soil water salinity on growth rate might be
 138 inconsistent considering a relative lower growth rate at Site 8 and 12 where soil water salinity was at intermediate level
 139 (17.5 ± 0.21 and $13.3 \pm 0.47 \mu\text{g L}^{-1}$). This inconsistency was probably due to the existence of micro-topography in form of
 140 the river levee at Site 8 and transgressed bedrock coast at Site 12. These micro-topography variations according to Thom
 141 (1982) can cause varying physiological responses in different species and there may be more or less favourable plant
 142 growth in a specific habitat due to the response of species to stress conditions.

143 Although soil water salinity was relatively higher ($19.7 \pm 1.25 \mu\text{g L}^{-1}$) at Site 10, growth rates of trees at this site were
 144 measured at medium growth rate. This rate of growth was probably affected by tidal inundation frequency of this site that
 145 was measured at 30 to 45% compared to 13 to 30% at Site 2 and 3. How trees of *B. gymnorhiza* and *R. apiculata* respond
 146 to specific conditions at Site 10 needs further investigation. The effect of salinity on mangrove growth has been reported
 147 by various studies (e.g. Robert et al. 2009; Meneses et al. 2003; Nasim et al. 2013; Noor et al. 2015). In Pakistan, for
 148 example, Nasim et al. (2013) reported that the maximum growth rate of *A. marina* was presumably due to low salinity and
 149 the minimum growth rate was related to higher salinity. Similar pattern was reported by Meneses et al. (2003) in the
 150 mangroves from Braganca Peninsula, North Brazil. In mangrove forests, conditions of high salinity can cause osmotic
 151 stress and reduce the availability of water, resulting in stomatal closure and reduced supply of carbon dioxide (Li et al.
 152 2008). Furthermore, membrane disorganisation and disturbance of nutrient balance may be induced by salt stress
 153 (Hasegawa et al. 2000).

Commented [KT6]: changed comma to point on the graph

Commented [KT7]: disorganization

116

117

118

119

120

121

122

123

124

125

126

127

128

129

130

131

132

133

134

135

136

137

138

139

140

141

142

143

144

145

146

147

148

149

150

151

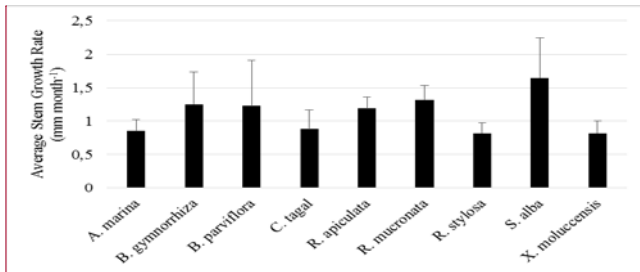
152

153

154

155 **Variation between species**

156 Figure 3 shows the stem growth rate for nine species. The result from the ANOVA statistical test indicated that average
 157 stem growth rate was significantly different between species ($F(8,243) = 7.063, p\text{-value} = 0.00, < 0.05$). A relatively
 158 highest growth was measured on *S. alba* ($1.65 \pm 0.69 \text{ mm month}^{-1}$) and a relatively lowest growth on *R. stylosa*, *X.*
 159 *moluccensis*, *A. marina*, *C. tagal*, measured at $0.82 \pm 0.16, 0.82 \pm 0.18, 0.85 \pm 0.18, 0.88 \pm 0.28 \text{ mm month}^{-1}$ respectively.
 160 A relatively medium growth rate was measured on *R. apiculata*, *B. parviflora*, *B. gymnorrhiza*, *R. mucronata*, measured at
 161 $1.19 \pm 0.16, 1.22 \pm 0.69, 1.25 \pm 0.49, 1.31 \pm 0.22 \text{ mm month}^{-1}$, respectively. When the growth rates were expressed as a
 162 percentage of the initial girth of each tagged tree, there was apparently higher stem growth rates on tagged trees of *B.*
 163 *gymnorrhiza*, *C. tagal* and *R. mucronata* with an initial girth of more than 50 cm compared to trees with an initial girth of
 164 less than 50 cm. Conversely, there was a relatively slower growth rate on tagged trees of *R. apiculata* and *S. alba* with an
 165 original girth of more than 50 cm compared to trees with an initial girth of less than 50 cm. For other species, comparison
 166 of growth rates between trees with an initial girth more than 50 cm and less than 50 cm was not evaluated because the
 167 absence of comparable data.
 168



Commented [KT8]: changed comma to point on the graph

169 Figure 3. Average stem growth rate of nine species over 59 months; error bars (Standard Deviations) represented variability over 59
 170 months
 171
 172

173 Table 2. Average stem growth rate (girth increment and as percentage of initial girth measured for nine species over 59 months); error
 174 bars (Standard Deviations) represented variability over 59 months, n represented number of tagged tree
 175
 176

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

177 Results from this study confirmed that the nine mangrove species had different growth rate, and the growth rate
 178 recorded in this study is different compared to those conducted elsewhere. For example, the annual diameter increment of
 179 *R. apiculata* was $0.32 \text{ cm year}^{-1}$ in mature mangrove forests in Malaysia (Putz and Chan 1986) and $0.25 \text{ cm year}^{-1}$ in the
 180 mangrove forests in Micronesia (Devoe and Cole 1998) which were lower than the average growth rate by this species in
 181 this study (0.45 cm/year). For *B. gymnorrhiza*, the annual growth increments were reported $0.35 \text{ cm year}^{-1}$ in Micronesia
 182 which were relatively lower compared to the growth rate of this species in this study ($0.48 \text{ cm year}^{-1}$). The annual diameter
 183 increments of *S. alba* were reported $0.49 \text{ cm year}^{-1}$ in the mangrove forests in Micronesia (Devoe and Cole 1998) which
 184 were relatively lower compared to the growth rates of these species measured in this study ($0.60 \text{ cm year}^{-1}$). Differences in
 185 growth rate of similar species from different places explained the important role of local environment and climatic
 186 condition to growth of mangrove species.
 187

188 In this study, large trees of *B. gymnorrhiza*, *C. tagal*, *R. mucronata* grew faster than small trees. The case for trees of *B.*
 189 *gymnorrhiza* and *R. mucronata* might explain that trees of these species remained at vigorous growth. Meanwhile, the case
 190 for trees of *C. tagal* might be different. Small trees of this species were found dominant at Site 2 and 3 where salinity is
 191 usually higher, and that trees are growing stunted at this condition. Sample of large trees of this species were found at Site

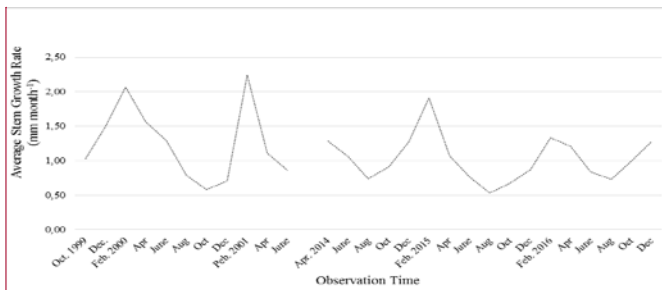
192 11 where soil water salinity was lower. Thus, in the case of *C. tagal*, differences in growth rate between small and large
193 trees were due to primarily soil water salinity.

194

195 **Seasonal variation**

196 Figure 4 shows average stem growth rates of 48 tagged trees selected from 12 different sites. This figure shows that
197 average stem growth rate started to increase in August or October over a year. This trend reached a maximum value in
198 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
199 month⁻¹ in February 2016. From February, stem growth rate decreased and reached minimum value around August and
200 October at different levels ranging from 0.53 mm month⁻¹ in August 2015 to 0.74 mm month⁻¹ in August 2014. Between
201 April 2015 and February 2016 there was abnormality in stem growth rate. During this period rates of average stem growth
202 rates were apparently low.

203



204

205

206

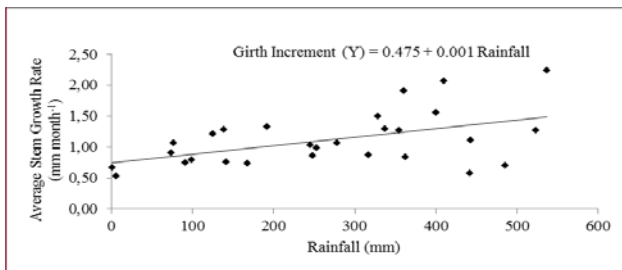
207

Figure 4. Temporal average stem growth rate over 59 months

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

214

215



216

217

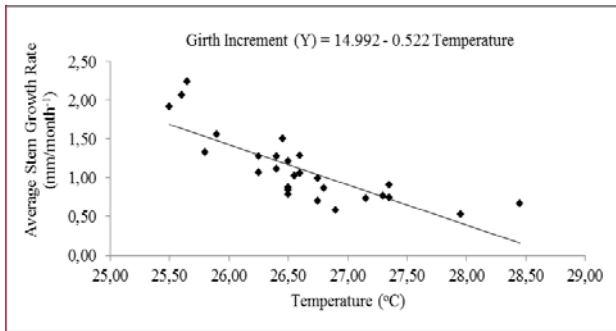
218

219

Figure 5. Relation between rainfall and stem growth rate

Commented [KT9]: changed comma to point on the graph

Commented [KT10]: changed comma to point on the graph



Commented [KT11]: changed comma to point on the graph

Figure 6. Relation between rainfall and stem growth rate

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 mm² 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 Niño-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 Niño on reduced growth rates was significant on mangroves in the study site.

ACKNOWLEDGMENTS

This research was supported in part by Ausaid-ADS Program. It is a pleasure to thank Brama Djabar for site map preparation, Kelola's staffs, Im and Mubin for field assistance, Professor Eugene Moll, Associate Professor David Lamb, Jim Davie, Norm Duke for supervision of the early work. I also thank Kate Night for helpful edits and comments.

REFERENCES

- 264 Clough BF. 1979. Mangrove ecosystem in Australia: structure, function and management. Proceedings of the Australian National Mangrove Workshop.
 265 Australian Institute of Marine Science, Cape Ferguson, 18-20 April 1979.
- 266 Day RH. 1990. Growth rates of three species of mangroves bordering Laguna de Terminos, Campeche, Mexico. [Thesis]. The University of Texas,
 267 Texas.
- 268 Devoe NN, Cole TG. 1998. Growth and yield in mangrove forests of the Federal States of Micronesia. *Forest Ecol Manag* 103:33–48.
- 269 Ding Hou. 1958. Rhizophoraceae. *Flora Malesiana*, 1(5):429-93.
- 270 Djamaluddin R. 2004. The dynamics of mangrove forest in relation to die-back and human use in Bunaken National Park, North Sulawesi, Indonesia.
 271 [Dissertation]. University of Queensland, Brisbane.
- 272 Djamaluddin R. 2018. The mangrove flora and their physical habitat characteristics in Bunaken National Park, North Sulawesi, Indonesia. *Biodiversitas*
 273 19(4):1303-1312.
- 274 Drexler JZ, Ewel KC. 2001. Effect of the 1997-1998 ENSO-related drought on hydrology and salinity in a Micronesian Wetland Complex. *Estuaries*
 275 24(3):347-356.
- 276 Duke NC, Botto MC, Ellison JC. 1998. Factors influencing biodiversity and distributional gradients in mangroves. *Global. Ecol Biogeogr* 7:27-47.
- 277 Duke NC. 1992. Mangrove floristics and biogeography. In: Robertson AI, Alongi DM (eds). *Coastal and Estuarine Studies*. American Geophysical
 278 Union, Washington.
- 279 Duke NC, Birch WR, Williams WT. 1981. Growth rings and rainfall correlations in a mangrove tree of the genus *Diospyros* (Ebenaceae). *Aust J Bot*
 280 29:135-142.
- 281 Giesen W, Wulffraat S, Zieren M, Scholten L. 2006. Mangrove guide book for Southeast Asia. FAO and Wetlands International.
- 282 Gill AM. 1971. Endogenous control of growth ring development in *Avicennia*. *For Sci* 17:462-465.
- 283 Hamilton SE, Casey D. 2016. Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century
 284 (CGMFC-21). *Global Ecol. Biogeogr* 25(6):729-738.
- 285 Hasegawa PM, Bressan RA, Zhu JK, Bohnert HJ. 2000. Plant cellular and molecular responses to high salinity. *Ann Rev Plant Phys* 51:463-499.
- 286 Jintana V, Komiya A, Moriya H, Ogino K. 1985. Forest ecological studies of mangrove ecosystem in Ranong, Southern Thailand - 4. Diameter
 287 growth measurement by dendrometry. In: *Studies on the mangrove ecosystem*. Nodai Research Institute (ed), Tokyo University of Agriculture,
 288 Japan.
- 289 Kairo JG. 2001. Ecology and restoration of mangrove systems in Kenya. Ph.D Thesis, Vrije Universiteit Brussel, Belgium.
- 290 Kathiresan K, Bingham BL. 2001. Biology of mangrove and mangrove ecosystem. *Adv Mar Biol* 40:81-251.
- 291 Krauss KW, Keeland BD, Allen JA, Ewel KC, Johnson DJ. 2006. Effects of season, rainfall, and hydrogeomorphic setting on mangrove tree growth in
 292 Micronesia. *Biotropica* 39(2):161-170.
- 293 Li N, Chen S, Zhou Z, Xy, Li C, Shao J, Wang R, Fritz E, Huttermann A, Polle A. 2008. Effect of NaCl on photosynthesis, salt accumulation and ion
 294 compartmentation in two mangrove species, *Kandelia candel* and *Bruguiera gymnorhiza*. *Aquat Bot* 88:303-310.
- 295 Maxwell GS. 2015. Gaps in mangrove science. *ISME/GLOMIS* 13(5):18-38.
- 296 Menezes M, Berger U, Worbes M. 2003. Annual growth rings and long-term growth patterns of mangrove trees from the Bragança peninsula, North
 297 Brazil. *Wetl Ecol Mang* 11:33-242.
- 298 Nazim K, Ahmed M, Shaikat SS, Khani MU, Ali QM. 2013. Age and growth rate estimation of grey mangrove *Avicennia Marina* (Forsk.) Vier from
 299 Pakistan. *Pakistan Journal Botany Pakistan J. Bot.* 45(2):535-542.
- 300 Noor T, Batool N, Mazhar R, Ilyas N. 2015. Effects of siltation, temperature and salinity on mangrove plants. *European Academic Research*
 301 II(11):14172-14179.
- 302 Noor YR, Khazali M, Suryadiputra INN. 2006. Mangrove introduction guide. Ditjen PPHKA-Wetland International, Bogor. [Indonesian]
- 303 Putz FE, Chan HT. 1986. Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia. *Forest Ecol Manag* 17:211-230.
- 304 Rajkaran A, Adams JB. 2008. The effect of sediment conditions on the growth rate of mangroves. *S Afr J Bot* 74(2):375-376.
- 305 Robert EMR, Schmitz N, Okello JA, Boeren I, Beechman H, Koedam N. 2011. Mangrove growth rings: fact or fiction. *Trees* 25:49-58.
- 306 Robert EMR, Schmitz N, Kirauni HA, Koedam N. 2009. Salinity fluctuations in the mangrove forest of Gazi Bay, Kenya: lessons to take for future
 307 research. *Nature and Fauna* 24:89-95.
- 308 Sobrado MA. 1999. Drought effects on photosynthesis of the mangrove, *Avicennia germinans*, under contrasting salinities. *Trees* 13(3):125-130.
- 309 Sobrado MA. 2006. Deferential gas exchange responses to salinity and drought in the mangrove tree *Avicennia germinans* (Avicenniaceae). *International*
 310 *Journal Tropical Biology* 54(2):371-375.
- 311 Spalding MD, Blasco F, Field CD. 1997. *World Mangrove Atlas*. International Society for Mangrove Ecosystems, Okinawa.
- 312 Srikanth S, Lum SKY, and Chen Z. 2015. Mangrove root: adaptations and ecological importance. *Tress* 30(2):451-465.
- 313 Suarez N, Sobrado MA, Medina E. 1998. Salinity effects on the leaf water relations components and ion accumulation patterns in *Avicennia germinans*
 314 (L.) seedlings. *Oecologia* 114:299-304.
- 315 Tomlinson PB. 1986. *The botany of mangroves*. Cambridge University Press, New York.
- 316 Valiela I, Bowen JL, York YK. 2001. Mangrove forests: one of the world's threatened major tropical environments. *BioScience* 51(10):807-815.
- 317 Verheyden A, Kairo JT, Beeckman H, Koedam N. 2004. Growth rings, growth ring formation and age of mangrove *Rhizophora mucronata*. *Ann Bot*
 318 94:59-66.
- 319