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PROJECTING CLIMATE CHANGE IMPACTS ON ABOVEGROUND BIOMASS OF TROPICAL FOREST IN EAST KALIMANTAN, INDONESIA

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Abstract: Tropical forest is highly vulnerable to severe changes in temperature and precipitation, because tree's biomass growth through photosynthesis is strongly related to those climate variables. Utilizing system thinking-based dynamic modelling, this study was mainly aimed to examine the impacts of future climate disturbances on aboveground biomass storage of three tropical tree species groups, namely *Shorea* spp., *Dipterocarpus* spp., and *Palaquium* spp. The final result of the study highlighted that when the dynamic simulation was run following five IPCC's climate change scenarios (Constant year 2000 concentrations, B1, A1T, A2, and A1F1), as well as a scenario of local climate projection for a simulation period of 200 years, the aboveground biomass stored in tree species of *Shorea* spp., *Dipterocarpus* spp., and *Palaquium* spp. will significantly decrease. This finding suggests that negative climate responses should be considered to improve long term sustainable forest management under incoming climate uncertainties. Therefore, several adaptation measures, such as selection of drought-tolerant varieties, assisted natural regeneration of functional species, or even under-planting of genotype of species adapted to expect future climate conditions should start to be considered seriously.

KEYWORDS: Climate change, aboveground biomass, tropical forest, *Shorea*, *Dipterocarpus*, *Palaquium*

Introduction
Climate Change

Nowadays, climate change has been considered as the most challenging issue confronting the sustainability of human activity in the 21st century (Banuri, 2009). The causes of this event have been elaborated in many studies, although the projections, models, and approaches are still contested (Schuur *et al.,* 2015). For example, climate risks that have been widely reported by Intergovernmental Panel on Climate Change (IPCC, 2007), as well as other related studies, such as Sneeringer (2009) and Stern (2007). With regard to Indonesia, a report by Case *et al.* (2007) contends that changes in climate variables, particularly temperature and precipitation, have already been felt in the country's territory. As cited in this report, the annual mean of temperature in Indonesia has considerably increased by approximately 0.3 ^{o}C, while in 1998 the increase was recorded almost 1^{o}C. In contrast with temperature, the report mentioned that precipitation patterns across all of Indonesia over the last decade has decreased by about 2-3%, while suggesting that there will be more intense *El Nino Southern Oscillation* (ENSO) vents in the future.

Similar to Indonesia, climate change has also been felt in its neighboring countries, including Malaysia and Brunei Darussalam. In order to assess changes in temperature and precipitation rate, government agencies in Malaysia has utilized a dynamic down-scaled "Regional Hydro-Climate Model for Peninsular Malaysia" (RegHCM-PM) and "Providing Regional Climates for Impacts Studies" (PRECIS). Both of those models suggest that at the end of 21st century there will be 1.5-2.0 oC increase in surface air temperature, while changes in precipitation rates spatially varies (MNREM, 2010). Meanwhile, a study by Hasan *et al.* (2016) report that surface temperature in Brunei Darussalam indicates significant increasing trends, with about 0.031 ^{o}C per year during the last 35 years.

Tropical Rain Forest Biomass

Photosynthesis has been widely acknowledged as the main mechanism for tropical forest trees to capture and store the most significant carbon emissions in the form of biomass. As mentioned by Sha *et al.* (2015), about 55% of annual net primary production (NPP) of biomass across the globe is estimated to take place in the tropics. Nevertheless, several authors such as Ma *et al.* (2014); Dai *et al.* (2014); and Ricker *et al.* (2007), have noted that such crucial role of tropical forest is highly vulnerable to extreme changes in temperature and precipitation. According to Tkemaladze and Makhashvili (2017), the impact of increasing temperature accompanied by decrease in water supply will sharply decrease photosynthetic activity of the leaves that eventually will drop the NPP of biomass. Taking into account all of those studies related to climate changes and photosynthesis, it appears that there is a need to assess how the biomass dynamics of tropical trees may react to climate change.

Previously, researchers have conducted studies in relation with climate influence on biomass accumulation in forest ecosystems. Hunter (2015) had evaluated the influences of temperature and rainfall on carbon stocks across Northeastern Part of New South Wales, Australia, while Limbu and Koirala (2017) had assessed climate influence at different altitudinal gradients on above and belowground carbon storage. Ma *et al.* (2014) had predicted the impacts of climate change on aboveground carbon storage rate in northeastern China. Stinziano and Way (2014) had calculated the effect of rising temperature on boreal forest. In addition, climate sensitivity of Mediterranean landscape has been investigated by Touchan *et al.* (2012). Many other researchers had also examined how the carbon stock and biomass accumulation were assessed either using terrestrial or remotely sensed data (Jaya *et al.,* 2012; Achmad, Jaya *et al.,* 2013; Jaya, 2014). Although all of those studies have provided important information on the impact of climate change on forest biomass, however, the dynamics of aboveground biomass storage under climate change scenarios in Indonesia, a country with the second largest tropical forest, are still unclear.

Insufficient information on ecosystem dynamic flow processes may result in the absence of a systematic and flexible method to manage and plan the ecosystem, so that temporal study and analysis of dynamic change of ecosystem service is necessary (Dominati *et al.,* 2010). Moreover, Dean *et al.* (2003) and Oni *et al.* (2012) contend that dynamic flow modeling and its corresponding analyses are crucial in providing a baseline and "what if" scenarios for evaluating effects related to climate disturbances. Considering these perspectives, this study primarily aims to examine the impacts of future climate disturbances on aboveground biomass (AGB) of three tropical tree species groups, namely *Shorea* spp., *Dipterocarpus* spp. and *Palaquium* spp. through "what if" scenarios, using system thinking-based dynamic modelling. Those three species groups were chosen since the type of forest in this study was categorized to lowland mixed dipterocarp forest, dominated by trees from Dipterocarpaceae family (Basuki *et al.,* 2009). Projections in this study were conducted based on five scenarios from Special Report on Emission Scenarios (SRES) by IPCC (2000), and one scenario following local climate trend. Dynamic modelling is appropriate to be utilized in this study because it is able to model processes that are time-dependent based on several scenarios simultaneously, as explained by Takolander (2013).

Materials and Methods

Study Area

As depicted in Figure 1, this study was conducted in East Kalimantan Province, Indonesia. The extent of this Province is about 127.26752 km^2, located between 113° 44' and 119° 00' east longitude, and between 2° 33' north latitude and 2° 25' south latitude. The area is mainly wavy and located between 0-1500 meters above sea level with average humidity approximately 83-87%. According to Basuki *et al.* (2009) the types of forest in this area were categorized as lowland mixed Dipterocarp forest, dominated by *Dipterocarpaceae* family.

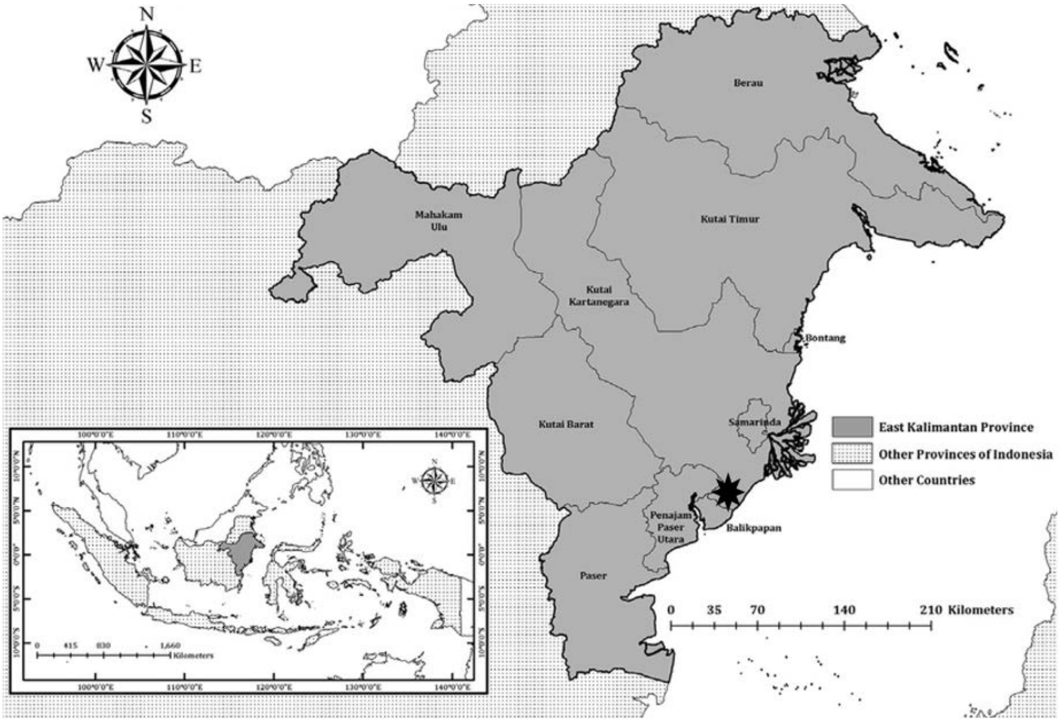

Figure 1: Study area (Kiswanto *et al.,* 2018).
✷ NCDC-Sepinggan climate station (966330)

Dynamic Model Conceptualization

Dynamic model structure for simulating relationship between local climate variables and aboveground trees' biomass in this study is illustrated in Figure 2. Meanwhile, algorithm details of the dynamic model are shown in Appendix 1. Conceptually, the dynamic model in this study was built to represent the whole process of trees' biomass growth. Parameters in this model were chosen based on previous study by Maulana and Wibisono (2017).

Conceptually, to begin with, through photosynthesis, trees convert carbon from the atmosphere to carbohydrate and stores it in different tree organs. This process of carbon capture is related to the process of tree growth (Sha *et al.,* 2015), and is influenced by climatic variables, especially temperature and precipitation rate (Theurillat & Guisan, 2001; Laubhann *et al.,* 2009; Allen *et al.,* 2010). In this study, the value of tree growth as a function of time was adjusted based on the value of annual increment calculated by Wahyudi and Anwar (2013), in which *Palaquium* spp. was grouped into harvested commercial species, while both *Myristica* spp. and *Syzygium* spp. were grouped into another commercial un-harvested species, as depicted in Table 1. Although in their study, Wahyudi and Anwar (2013) have used the term of Mean Annual Increment (MAI), however, according to several other studies such as Vanclay (1994), Avery and Harold (2002), and Pretzsch (2009), it seems that the term Periodic Annual Increment (PAI) is more relevant to represent the growth of tree species in natural forest because basically there is no age information for those natural tree species.

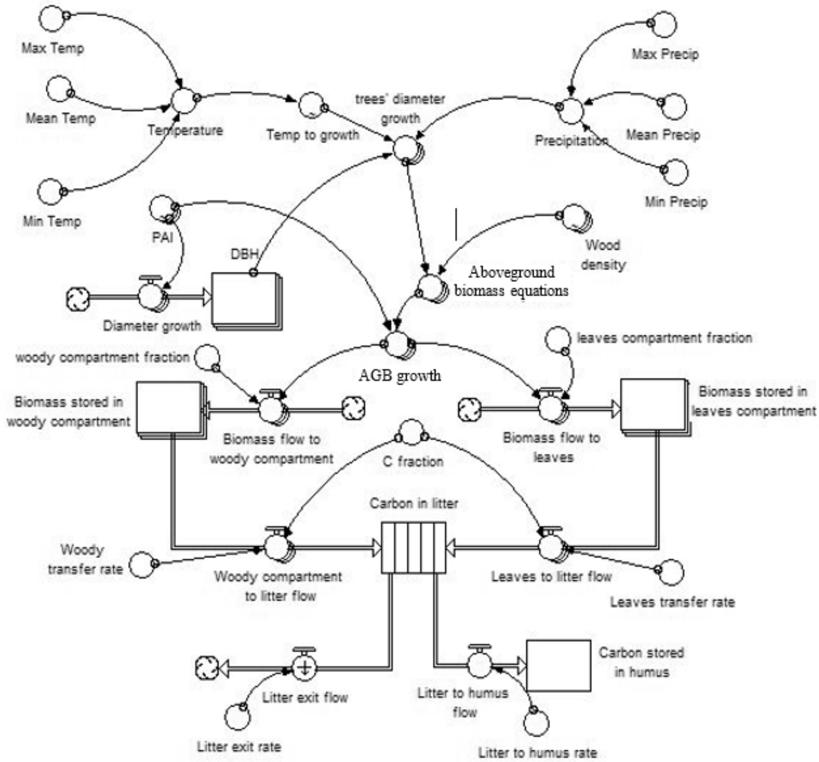

Figure 2: Dynamic model structure for projecting climate change impacts on aboveground trees' biomass.

Table 1: Trees' periodical annual increment (PAI).

DBH Class (cm)	*Shorea* PAI (cm/year)	*Dipterocarpus* PAI (cm/year)	*Palaquium* PAI (cm/year)
10-19	0.3809	0.3791	0.2158
20-29	0.5839	0.6271	0.3408
30-39	0.6869	0.7551	0.4058
40-49	0.6899	0.7631	0.4108
50-59	0.5929	0.6511	0.3558
>60	0.3959	0.4191	0.2408

Source: Wahyudi and Anwar (2013)

Obtained PAI data, as illustrated in Table 1, were then used to estimate the tree growth period (TGP) for each DBH class. For the beginning of the growth period, due to the unavailability of PAI data for DBH class less than 10 cm, the simulation at year 0 was set using initial DBH of 10 cm. From that point forward, TGP was calculated by dividing the interval of each DBH class (cm) with its corresponding PAI (cm/year) as depicted in Table 2 below.

Table 2: Calculation of Tree Growth Period (TGP) and its simulation time step.

DBH class		10-19 cm	20-29 cm	30-39 cm	40-49 cm	50-59 cm	> 60 cm
TGP calculation		(19-10)/ PAI	(29-20)/ PAI	(39-30)/ PAI	(49-40)/ PAI	(59-50)/ PAI	
Shorea	TGP (Years)	24	15	13	13	15	> year 82
	Time step	year 1 to 24	year 25 to 39	year 40 to 53	year 54 to 66	year 67 to 81	
Dipterocarpus	TGP (Years)	24	14	12	12	14	> year 77
	Time step	year 1 to 24	year 25 to 38	year 39 to 50	year 51 to 62	year 63 to 76	
Palaquium	TGP (Years)	42	26	22	22	25	> year 142
	Time step	year 1 to 42	year 43 to 69	year 70 to 92	year 93 to 115	year 116 to 141	

In the meantime, values of wood density (WD) were taken from Basuki *et al.* (2009). As shown in Table 3, wood density for each species group is detailed, namely for *Shorea* spp., *Dipterocarpus* spp., and *Palaquium* spp. are 0.39-0.61 gr/cm^3, 0.64-0.73 gr/cm^3, 0.58-0.63 gr/cm^3 respectively. Afterwards, biomass accumulation into the system through photosynthetic activity was calculated using locally developed allometric equations, which were specifically designed for above mentioned tree species groups in the research area also by Basuki *et al.* (2009), as detailed in Table 4. Meanwhile, carbon content in tree components was determined using biomass to carbon ratio value established by Hairiah and Rahayu (2007) that is 46%, so that carbon quantity in each component was defined by multiplying the dry weight of corresponding components by the percentage of the carbon amount.

Table 3: Wood density.

Shorea						
Diameter (cm)	10-19 cm	20-29 cm	30-39 cm	40-49 cm	50-59 cm	>60
Wood Density (gr/ cm3)	0.39	0.5	0.51	0.54	0.6	0.61
Dipterocarpus						
Diameter (cm)	10-19 cm	20-29 cm	30-39 cm	40-49 cm	50-59 cm	>60
Wood Density (gr/ cm3)	0.64	0.7	0.7	-	-	0.73
Palaquium						
Diameter (cm)	10-19 cm	20-29 cm	30-39 cm	40-49 cm	50-59 cm	>60
Wood Density (gr/ cm3)	0.58	-	-	0.59	0.6	0.63

Source: Basuki *et al.* (2009)

Table 4: Aboveground biomass equations.

		Shorea				
Species group	Biomass allometric	Coefficient		Standard error of the coefficient	R-sq (adj)	Standard error of residual
Shorea	ln(AGB) = c + a ln(DBH) + b ln(WD)	c	-1.533	0.405	0.986	0.244
		a	2.294	0.07		
		b	0.56	0.278		
Dipterocarpus	ln(AGB) = c + a ln(DBH) + b ln(WD)	c	-1.19	0.336	0.989	0.213
		a	2.175	0.057		
		b	0.082	0.488		
Palaquium	ln(AGB) = c + a ln(DBH) + b ln(WD)	c	-0.723	0.286	0.98	0.201
		a	2.145	0.071		
		b	0.704	0.273		

Source: Basuki *et al.* (2009)

Initial dynamic simulation was set based on climate time series data of perceived temperature (1974-2017) and precipitation (1979-2017) that were supplied by the NOAA-National Climatic Data Center (NCDC) from its climate station (Station ID: 966330) in Sepinggan-East Kalimantan, located between 1° 15' 56.9340" south and 116° 53' 51.8208" east. Local climate data from this station before 1974 for temperature and before 1979 for precipitation are unavailable, hence the data only limited starting from 1974 and 1979 forward. According to these climatic data trends, the annual range of temperature and precipitation in the research area were about 24.69 ^{o}C to 30.39 ^{o}C and 361.53 mm/year to 2454.33 mm/year respectively.

Subsequently, projections toward future probabilities of climate disturbances were conducted using scenarios described in Special Report on Emission Scenarios (SRES) by IPCC (2000), as well as scenarios based on local climate projection. Overall, according to IPCC (2000), the first scenario that is constant year 2000 assumes that greenhouse gases concentration is held fixed at year 2000 levels. Hence this scenario put the lowest projection of temperature increase at 0.6 ^{o}C. The B2 scenario describes a world with less rapid economic and population development due to increasing attention to environmental sustainability. The A1T scenario illustrates a future world with rapid introduction of new technologies of non-fossil energy sources. The A2 scenario considers fragmented technological and economic development. Lastly, The A1FI scenario puts more emphasis on the intensive development of fossil fuel based industries, so that this scenario gets the highest estimate of temperature increase of 4 ^{o}C.

In the meantime, as suggested in Gardner and Urban (2003), in order to examine the impact of future climate disturbances on carbon storage of each species group, results from dynamic simulations based on both IPCC scenarios and local climate projection were then compared to results of their dynamic modelling at baseline/ normal climate condition harnessing their percentage value of deviation, while statistically examined based on paired t-test mechanism.

Results and Discussion

Local Climate Projection and Global Climate Scenarios

After statistically analysing local climate data trend for both of temperature and precipitation, as illustrated in Figure 3, it can be seen that there was a significant increasing trend in temperature, with about 0.011 annualy (p=0.006). Projection of this trend to the end of 21st century (2099) will result in temperature increase about 2.6 ^{o}C. On the other hand, although it seems there was a decreasing trend in precipitation, however, this trend is statistically insignificant. Nevertheless, as illustrated in Figure 3, with about 5.6 mm/year decreasing trend in precipitation, the projection of this value to the end of 21st century (2099) will produce approximately 29% average decrease in precipitation rate.

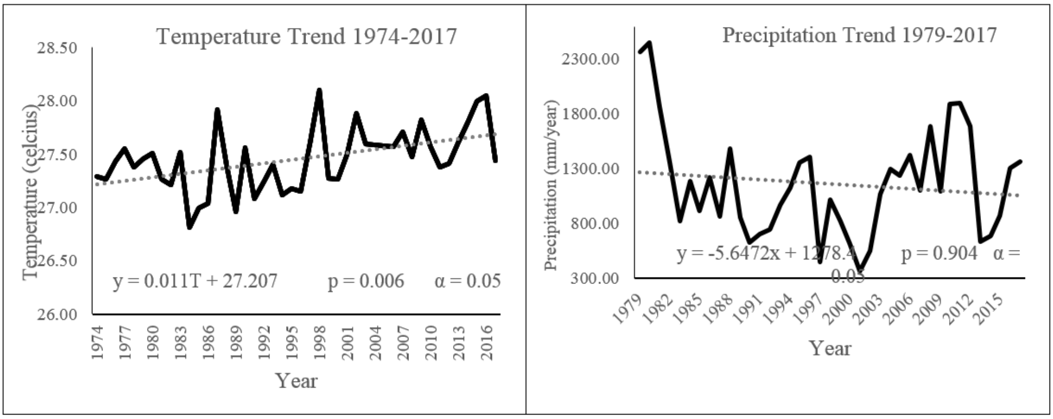

Figure 3: Local climate trend.

Projections of Aboveground Biomass Based on Global and Local Climate Scenarios

In general, as illustrated in Figures 4, 5 and 6 there were dynamic fluctuations of carbon storage for each species when climate parameters within the dynamic model were set following future scenarios as described by IPCC (2000), as well as local climate projection. At first, the aboveground carbon storage for each tree species were relatively stable when the model was run based on the "constant year 2000 concentrations" scenario, where the assumption was a 0.6 oC temperature increase and about 20% precipitation decrease. Nevertheless, from that point forward, the aboveground carbon stored in the system generally started to significantly decrease when the climate parameters were adjusted to more extreme scenarios, namely B1, AIT, local climate projection, A2, and A1FI. This kind of fluctuation may occur since at warmer temperature and lower precipitation compared to normal condition, broadleaf trees tend to decrease their photosynthetic productivity while increase littering pace to sustain their metabolism equilibrium which eventually hamper their growth and reduce carbon storage capacity (Heimann & Reichstein, 2008; Omeja *et al.,* 2012; Wang, 2012).

The detailed projections of Intergovernmental Panel on Climate Change [IPCC] (2000) climate scenarios on carbon storage for each species from Figures 4, 5, and 6 are shown in Table 5. The table, apparently describes that future rise in temperature and decrease in precipitation rate will reduce carbon storage capacity for all species. Furthermore, climate change will cause the largest impact in scenario A1F1 where there is 4 ^{o}C increase in temperature range coupled with 20% reduction in precipitation. At this scenario, aboveground carbon stored in the trees from species of *Shorea* spp., *Dipterocarpus* spp., and *Palaquium* spp. will decrease approximately 16.62%, 15.84% and 16.14% respectively during 200 years of simulation period.

Table 5: Climate scenarios at the end of 21st century (2090-2099).

Scenario	Temperature increase (°C)		Average decrease in precipitation	Sources
	Best estimate	Likely range		
Constant year 2000 concentration	0.6	0.3-0.9	20%	IPCC (2000)
B1	1.8	1.1-2.9		
A1T	2.4	1.4-3.8		
A2	3.4	2.0-5.4		
A1FI	4.0	2.4-6.4		
Local climate projection	2.6	0.9-4.3	29%	Calculated based on NOAA-GSOD data from Sepinggan station, East Kalimantan-Indonesia

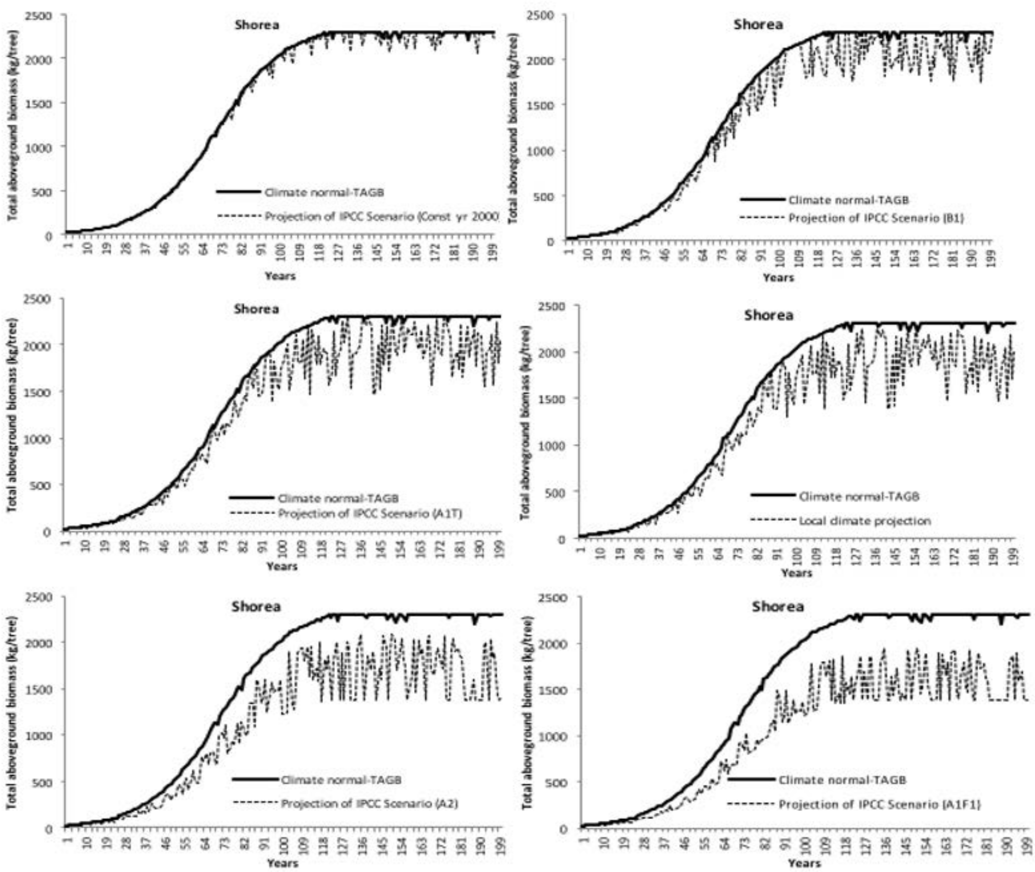

Figure 4: Projection of future climate change scenarios (Constant year 2000 concentrations, B1, A1T, Local Projection, A2, A1F1) on aboveground biomass of *Shorea* spp. for 200 years simulation period.

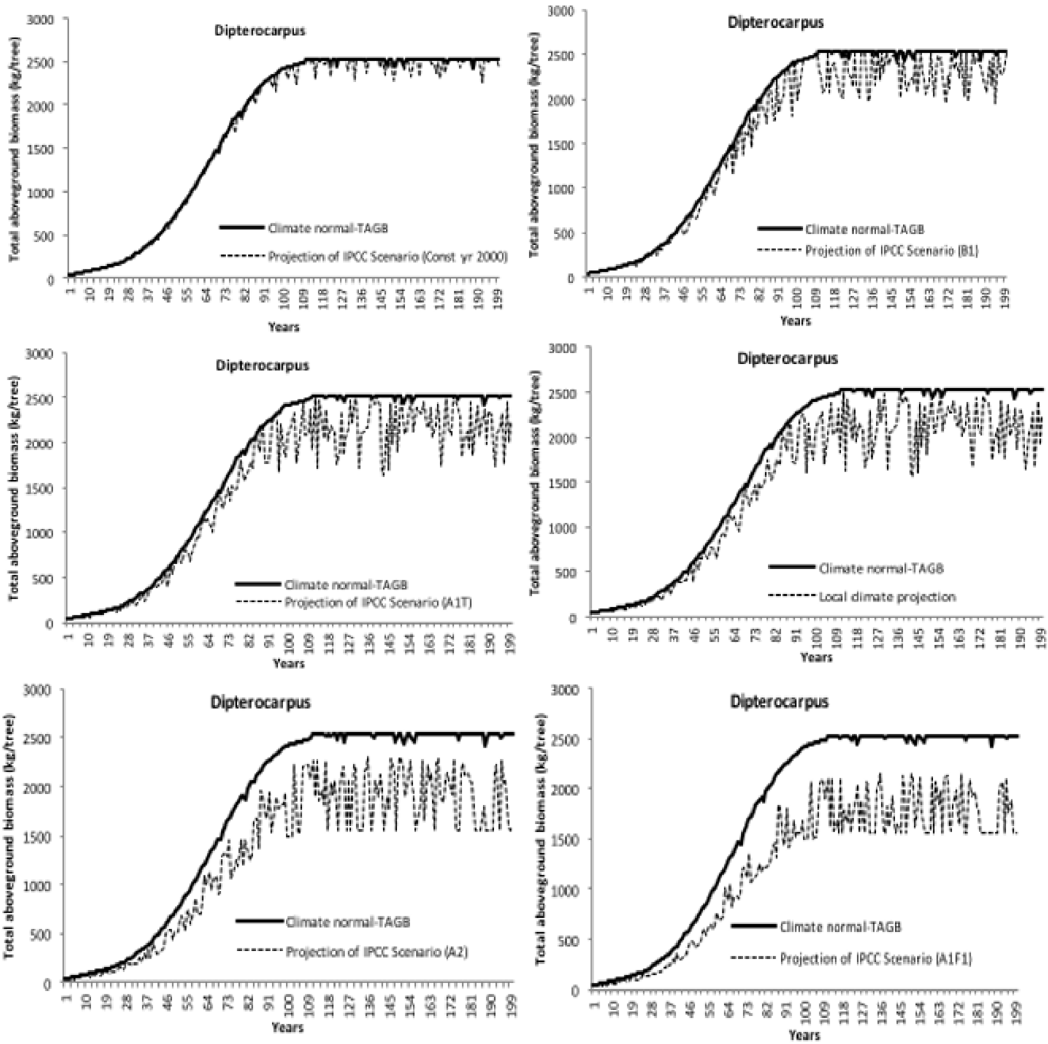

Figure 5: Projection of future climate change scenarios (Constant year 2000 concentrations, B1, A1T, Local Projection, A2, A1F1) on aboveground biomass of *Dipterocarpus* spp. for 200 years simulation period.

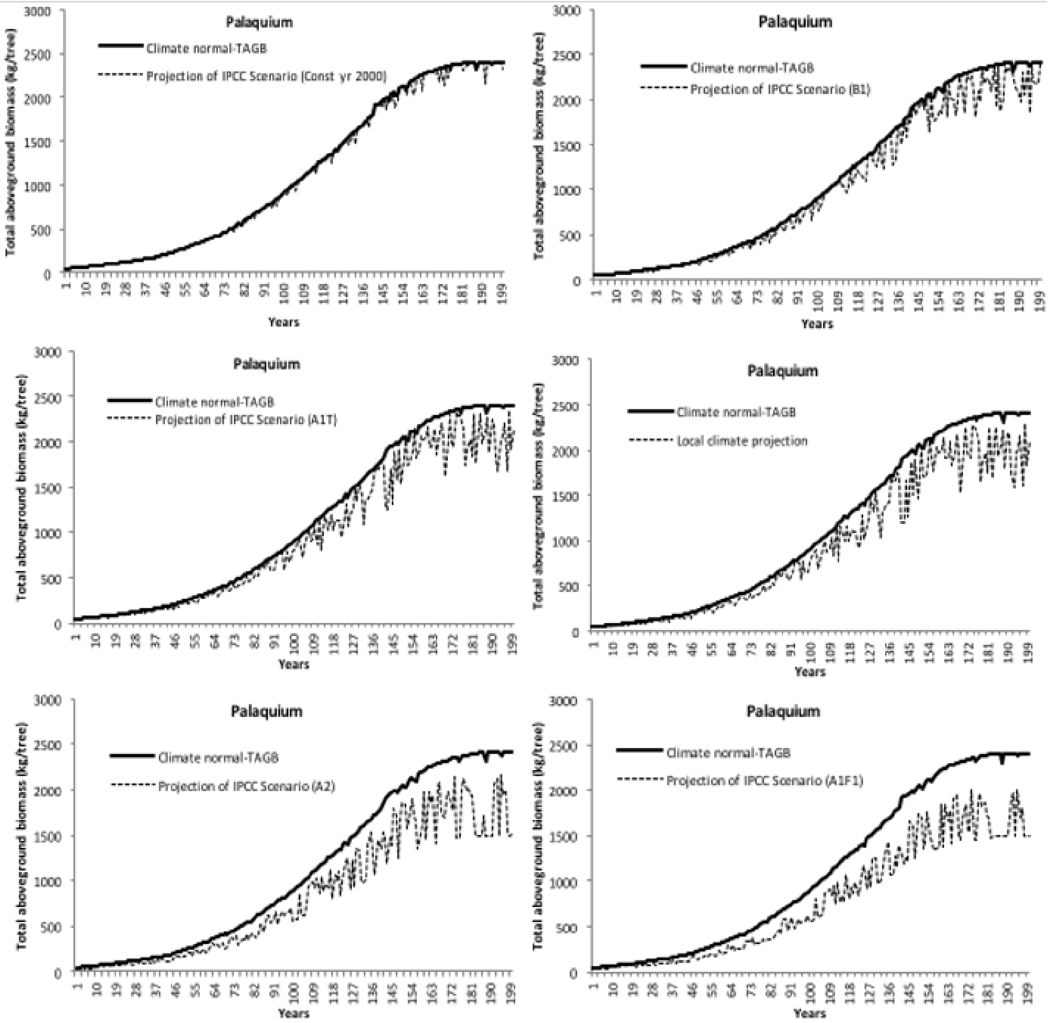

Figure 6: Projection of future climate change scenarios (Constant year 2000 concentrations, B1, A1T, Local Projection, A2, A1F1) on aboveground biomass of *Palaquium* spp. for 200 years simulation period.

Table 6: Aboveground biomass (AGB) projection based on future climate scenarios.

Compared to climate normal AGB		IPCC SRES Scenarios					Local climate projection
		Const yr 2000	B1	A1T	A2	A1F1	
Shorea	Deviation (S)	-2.25%	-9.33%	-13.52%	-25.47%	-32.11%	-16.62%
	t-value at 95% CI	5.96**	11.56**	13.75**	18.62**	21.33**	14.73**
	t-table (CI: 95%)	1.66	1.66	1.66	1.66	1.66	1.66
	P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Dipterocarpus	Deviation (S)	-2.13%	-8.89%	-12.87%	-24.43%	-30.86%	-15.84%
	t-value at 95% CI	6.09**	11.9**	14.32**	19.62**	22.66**	15.37**
	t-table (CI: 95%)	1.66	1.66	1.66	1.66	1.66	1.66
	P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Palaquium	Deviation (S)	-2.48%	-9.25%	-12.85%	-24.04%	-30.45%	-16.14%
	t-value at 95% CI	5.39**	10.1**	11.62**	14.55**	16.38**	12.33**
	t-table (CI: 95%)	1.66	1.66	1.66	1.66	1.66	1.66
	P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Figure 7 shows the projection of aboveground biomass, derived from Table 6. It is clearly shown that *Shorea* spp., *Dipterocarpus* spp., and *Palaquium* spp. are becoming more vulnerable when climate scenario worsens. Moderate climate change scenarios, such as Constant year 2000, has already brought significant statistical deviation to all of those species groups. In addition to this, looking at the more extreme climate scenario of B1 and A1T, it seems that *Dipterocarpus* spp. has the lowest decrease in aboveground biomass, while *Shorea* spp. tends to produce the highest rate of decrease compared to the two other trees species. This finding is in agreement with several previous studies which have showed that the growth and productivity of many broadleaf trees with the lowest wood density value among their corresponding groups, is more vulnerable when temperature becomes warmer (Bennett *et al.,* 2013; Coops & Waring, 2011; Subedi & Sharma, 2013; Hu *et al.,* 2015). Taking into account of this notion, compared to *Dipterocarpus* spp. and *Palaquium* spp. (Table 3), *Shorea* spp. has the lowest range of wood density with only 0.39-0.6 gr/cm^3 in contrast with *Dipterocarpus* spp. that has the highest range of wood density with about 0.64-0.73 gr/cm^3.

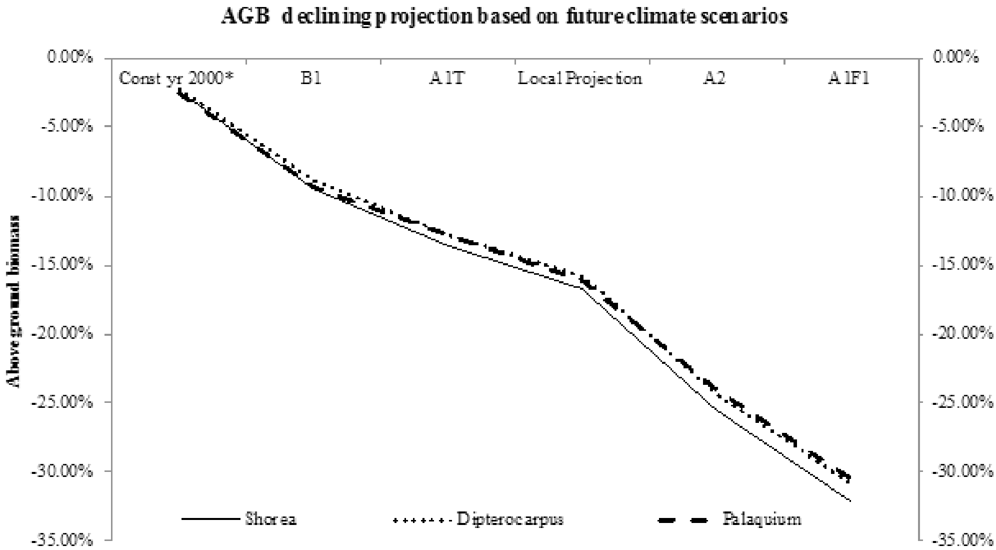

Figure 7: AGB declining projection based on future climate scenarios.

This study noted that although the simulation findings may provide a feasible approach to analyze model dynamics, however, it should be kept in mind that the simulation aboveground carbon storage on various climate change scenarios are complex flow processes. The users may improve the accuracy of the dynamic model by appropriately considering the possible shortcomings, particularly in regard to tree growth calculation. Looking at the periodical annual increment of each tree species (Table 1), it seems that the growth rates are too slow. The PAI for *Palaquium* spp. is only limited to 0.22 – 0.41 cm/year, while *Shorea* spp. is about 0.38 – 0.68 cm/year and *Dipterocarpus* spp. is about 0.37 – 0.76 cm/year. Those relatively small annual increments have also been reported by other studies, such as Santoso (2008), and Wahjono and Anwar (2008), who conducted measurements on permanent sample plots (PSPs) in 199 forest consessions across Indonesia. Although the use of tree growth data obtained from permanent sample plots (PSPs) of other studies, as mentioned in the methodology of this study, may inflict bias, however, this kind of approach should be considered as an acceptable alternative because detecting trends in tree growth over natural forest stands is not so simple (Bowman *et al.,* 2013). In practice, measuring tree growth in PSPs of natural forest are indeed not only very time-consuming to conduct, but also highly logistically demanding since they are often located in remote species rich forets areas (Bowman *et al.,* 2013; Weiskittel *et al.,* 2011).

Conclusion

This study, produces a through dynamic modeling, which is considered robust compared to previous modeling methods that generally relied upon a mere static approach. A dynamic model accounts for time-dependent changes in the state of the system, while a static (or steady-state) model calculates the system in equilibrium, and thus is time-invariant. The study concludes that climate negative response should be considered to ensure the accuracy of long term forest carbon accounting under future climate uncertainties. The dynamic simulation was run following five IPCC's climate change scenarios (Constant year 2000 concentrations, B1, A1T, A2, and A1F1), as well as a scenario of local climate projection for a simulation period of 200 years, the aboveground biomass stored in tree species of *Shorea* spp., *Dipterocarpus* spp., and *Palaquium* spp. will significantly decrease. This finding also implies that forestry-related governmental agencies and private sectors, should anticipate longer growing period and decrease in wood productivity, particularly in forest plantations. Therefore, it seems that both of forest managements and practices may also need to be adapted to reduce forest vulnerability. Several adaptation measures, such as selection of drought-tolerant varieties, assisted natural regeneration of functional species, or even under-planting of genotype of species adapted to expect future climate conditions should start to be considered seriously.

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