Standing carbon in an urban green space and its contribution to the reduction of the thermal discomfort index: a case study in the City of Banjarbaru, Indonesia

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Abstract- The ecological benefit of trees in an urban green space in the city of Banjarbaru was investigated during the long dry season of 2011. About 19 ha of homogenous green space, consisting of approximately 3770 *Pinus merkusii* trees, was studied in order to assess the trees' biomass, carbon stock, carbon sequestration and ability to reduce human thermal discomfort. Above ground fresh and total dry biomass was calculated using an allometric equation of the DBH (Diameter Breast Height) of 404 trees. Carbon storage and sequestration were calculated as a portion of total carbon by considering the pine growth factor. These figures were supplemented by calculation of balanced CO_2 for and O_2 produced by photosynthesis. The result reveals that the DBH of the trees is distributed into 9 classes, mostly with an interval of approximately 35.5 – 41.4 and 41.5 - 47.4 cm, with others distributed from 23.9 cm to 76.4 cm. Biomass consisted of 0.032 $Ggha^{-1}$ total carbon and of 0.025 $Ggha^{-1}$ carbon storage. There were also 2,216,915 tons or 883.441 $kgha^{-1}$ balanced CO_2, and 21,134.064 ty^{-1}potential carbon sequestration. Also, local people can benefit from additional oxygen of 56,357.505 ty^{-1}, which is enough to supply the needs of about 5 % of the local district population. Pine Park provides a cooling effect by giving a reduction on THI of 6 °C to 7 °C from exterior value of 32 °C. Thus, this study concludes that Pine Park in the city of Banjarbaru is effective in mitigating the effects of climate change and situations of extreme heat.

***Index Terms*:** Diameter Breast Height (DBH), Temperature Humidity Index (THI),

I. INTRODUCTION

THe benefit of trees in an urban green space was investigated from a different point of view to that in developed countries. Urban populations derive either direct or indirect benefits from green space. These include carbon sequestration, reduction of storm risk and mitigation of the effects of storms, absorption of urban emissions and production of oxygen, purification of air and water, noise reduction, microclimate regulation, promotion of urban health, conservation of biodiversity and soil-water protection (Cicea and Pirlogea, 2011; Seaman et.al., 2010; Burl et.al., 2007; Baris, et.al. 2009; Davies, et.al., 2008; Abkar, et.al., 2010; Akbari et.al., 2001).

Economic benefits, such as local income generation and the increase of home prices, and social benefits, including social relationships, can influence several health outcomes; the current research has shown trends in urban cohesiveness and democracy. Furthermore, there is increasing evidence for a positive relation between green space and health and there are indications of a positive relation between the amount of green space in the living environment and social relationships (Maas, et.al., 2006, 2009; Szumacher, 2011; Altunkasa and Uslu, 2004; McPherson et.al., 2005)

City is dependent of urban internal capability and other factors beyond the city limit. Locally generated ecosystem services have a substantial effect on quality-of-life in urban area and should be addressed to land use planning, such as green open space and city gardens. Green space improves the urban environment and contributes to public health and the quality of urban life (Zhou et.al., 2011; Gabor and Jombach, 2009; Taib, et.al., 2007; Yilmaz and Toy, 2007)

Green space is very important in supporting sustainable development in the City of Banjarbaru, a small metropolitan area with a population of about 170,000. The City of Banjarbaru is a newly emerging and fast growing city under autonomic regulation and has great potential for becoming a metropolitan region, named "Banjar Bakula," through the acquisition of services from four other cities. Currently, the City of Banjarbaru is a Provincial Administrative City of South Kalimantan Province. Thus, quantity and quality of green space will become obviously important in the regional response to climate change.

The biggest green space in the City of Banjarbaru is Pine Park, a homogenous *Pinus merkusii* forest of about 19 ha. It is very close to a residential settlement and serves people from a few yards to several kilometers. The users of this forest are families, teenagers and school children, and it is used for walking, cycling or camping and picnics or family gatherings. Most people recognize the benefit of Pine Park, but there is has been little scientific evaluation of these benefits.

The City of Banjarbaru is also threatened by urbanization, and the proven gradual deterioration of urban ecosystems due to poorly planned urban industrial development, low level management and over exploitation of natural resources, especially water and land resources, presents a challenge for sustainable social and economic development in the emerging city. The principle of ecological balance can be used to plan the amount of urban green space. The element threshold method is very useful in developing countries, where many habitats have been disturbed by human activities. In Banjarbaru, this method is more relevant than are some others, such as the ecological factor plat method and the recreation space ratio method (Zhang, et.al., 2007)

This research is aimed both at identifying ecological elements, including the carbon-oxygen balance and thermal comfort, that are potentially relevant in relation to reducing the negative impacts of climate change and at assessing ecological benefits, such as biomass, carbon storage and sequestration and balanced carbon for and oxygen produced from photosynthesis. In addition, the local humidity and temperature in the interior of Pine Park were measured in order to calculate the thermal discomfort index.

II. Method

About 404 trees were sampled from 21 sample plots in 19 ha of green space. Plots were set up following three replicated transect lines, with 7 (20 x 20 m) plots in each line, which were positioned opposite to each other. The DBH (Diameter Breast Height) of trees was calculated from the circumference, measured using a meter band at 1.37 cm from the ground. A klinometer was used to estimate tree height. Dead trees were not measured, because about 169 dying and dead trees were cut in early 2011 for safety reasons, at the suggestion of park users. As there are no data for those removed trees, the total carbon storage with the dying or dead trees was not taken into account (Nowak, 1993; Nowak et.al., 2003).

Data were arranged statistically in 9 classes based on class intervals of DBH. Although maximum and minimum population range intervals were not assessed statistically, frequency of class interval was used for multiplying the proportion of the population when calculating the total number of the population, about 3770 trees (Velle, 1995).

Measurement and prediction of carbon content by destructive methods can not be used for urban trees. Therefore, fresh biomass was calculated using the allometric equation,

$$Y = 0.1\ (DBH)^{2.29} \quad \text{...............(1)},$$

where Y is above ground fresh biomass in kg, DBH is the diameter breast height (cm) and 0.1 is a species specific coefficient. Nowak and Crane (2002) suggest using factor conversions of 0.48, for calculating a proportion of dry biomass from fresh biomass, and of 0.46, for converting dry biomass to above ground carbon. In addition, total carbon also was calculated from above carbon by considering a root-shoot ratio of 0.26. Total carbon was multiplied by a conversion factor of 3.666 to find out the amount of balanced CO_2 for photosynthesis. Potential carbon sequestration was calculated as the difference of total carbon in the next year, by considering a *Pinus merkusii* growth factor of 0.26 cm DBH per year. Oxygen production was determined by multiplying carbon sequestration by a conversion factor of 1.2 (Ritson and Sochachi, 2003; Siregar, 2007, 2011; Wang et.al., 2004; Nowak et.al., 2000, 2007).

Human respiration consumes about 800 g and for biochemical oxygen consumption is about 40 g per person each day. Annual oxygen consumption is approximately Total population x 0.000840 x 365 days = Total population x 0.3066 ty^{-1} (tons per year). The Indonesian gasoline emission factor is 69,300 kg TJ^{-1} CO_2, so the fuel emits about 2.223 kg CO_2/l (Wong and Gong, 2002; Hill et.al., 2011).

Air temperature and relative humidity (Rh) were measured using a digital thermometer and hygrometer (Kestrel 4500, Nilesen-Kellerman, NS:626643, USA). The human thermal discomfort index, was calculated from the air temperature and Rh from the interior and the exterior of the forest Park using the equation,

$$THI = 0.8\ Ta + (Rh \times Ta)/500 \quad \text{..........................(2)},$$

where THI is the Temperature Humidity Index, Ta is the air temperature at 1.5 m from the ground (^oC) and Rh is the relative humidity at 1.5 m from the ground. Empirical testing of the THI value using human subjects enabled the comfort limit to be defined as follows:

$21 <= THI <= 24$ is 100% of subject felt comfort,
$24 <= THI <= 26$ is 50 % of subject felt comfort,
$THI > 26$ is 100% of subjects felt discomfort.

Temperature and Rh were measured in each plot at 06:00 am, 11:00 and 03:00 pm four times within the long dry season, from July to September 2011. THIs from the interior and exterior of Pine Park were compared to reveal the role of these trees in the reduction of thermal discomfort, as this has been investigated in many developed countries (Tahbaz, 2011; Poupkou, et.al., 2011; Kakon, et.al. 2010; Georgi and Zafriadis, 2006; Wang, 2004; Kamoutsis, et.al., 2010)

III. Result and Discussion

The geographical location and topography positions of the City of Banjarbaru are favorable in relation to it becoming the center of urban regional development. There are transitions of land use from green space to built environment, such as urban settlement, market blocks, industrial and mining facilities. Pine Park has been reduced from 24 ha to just 19 ha due to urban settlement development. There is some dispute about further uses of Pine Park, and there is insufficient research about the benefits of Pine Park to support decisions over whether to hold or to convert its function.

All of the pine trees were planted in 1968 for reforestation; the park was initially a nursery for pine in South Kalimantan. The ages of the trees are not less than 45 years. The project was discontinued because *P. merkussii* produces resin that is easily fired during the dry season, and this nursery was overlooked for years. Now, the City government needs it to maintain a balance between green and built areas.

Above carbon

Trees in Pine Park were planted about 3 m from each other, and the average density is 198 trees/ha^{-1}. Individual tree canopies overlap, but there some gaps in the overall canopy that allow sunlight to reach the forest floor. Although some plant species grow under the canopy, carbon from the litters and under storey plants was not measured because, in this dry season, all of them have been slashed and burned for annual maintenance.

Calculation of carbon may become an indicator of a sustainable urban response to climate change, in term of local climate mitigation.. Multiplying 0.48 with the fresh biomass of 404 sample trees resulted in 2824.5 kg above ground dry biomass, and multiplying this amount of dry biomass by a conversion factor of 0.46 and a 0.26 root-shoot ratio equals to 1637.1 kg of total carbon storage (Nowak 2004, 2008).

DBH was distributed into 9 classes of stem. Most trees had a DBH of approximately 35.5-41.4 and 47.5-53.4 cm , while others ranged from 23.9 cm to 76.4 cm. The dry biomass maximum, minimum, average weight and standard deviation were calculated and are presented in Table 1. Wide variation of DBH are expressed by high value of it's standard deviation. As McPherson (1998) found in Sacramento urban forest, carbon storage reflected in differences in tree size and diameter may be related to competitive responses to the need for light and the crowding of plants and those competition is dynamic in climatic condition and disturbance by anthropogenic activities (Sanchez-Gomez, 2008; Comes and Allen, 2007; Canham, et.al., 2004; Hartmann and Messier, 2011).

Extrapolating values from samples to total trees in 19 ha Pine park produced a result of 0.021151 $Ggha^{-1}$ and 0.016786 $Ggha^{-1}$ of total carbon and carbon storage, respectively. This equates to 77.538 tons of CO_2 absorbed and potential carbon sequestration of 588.538 ty^{-1}. According to the Indonesian Country Study Ministry of Environment Republic of Indonesia (1999), this amount of balanced carbon of 77.538 ty^{-1} is equal to 46 524.58 liter burned gasoline or about 3 877 048 km journey for a small car with a fuel consumption of 12 km/l (Djajadilaga et.al., 2009; Zhang et.al., 2007).

Table 1. Dry Biomass, Carbon content and Oxygen production

Class of DBH	n	Dry Biomass			Carbon (extrapolated for 19 ha park)				Oxygen produced (ty^{-1})
		Maximum tones	Minimum tones	Average +/- tones	Total (Gg)	Storage (Gg)	Balanced CO_2 (ty^{-1})	Sequestration (ty^{-1})	
23.5-29.4	18	68.732578	109.7353285	90.61 +/- 20.29	0.009	0.007	32.345	517.082	1,378.885
29.5-35.4	61	112.48595	165.2196099	142.60 +/- 20.10	0.047	0.037	172.409	2,255.123	6,013.661
35.5-41.4	133	172.17957	242.2158841	214.80 +/- 22.80	0.155	0.123	566.409	6,184.982	16,493.285
41.5-47.4	76	250.83414	325.9655259	285.47 +/- 29.97	0.117	0.093	430.060	4,145.349	11,054.264
47.5-53.4	60	336.14088	429.8263761	370.77 +/- 50.44	0.120	0.096	441.184	3,788.344	10,102.250
53.5-59.4	45	435.74318	543.3699305	471.16 +/ - 70.90	0.115	0.091	420.471	3,249.947	8,666.526
59.5-65.4	6	566.51003	586.5991052	579.00 +/- 216.67	0.019	0.015	68.895	486.612	1,297.631
65.5-71.4	3	1563.2211	1707.469984	1629.06 +/- 815.21	0.013	0.010	46.522	287.883	767.689
71.5-77.4	2	928.08105	985.2014186	956.64 +/- 551.90	0.010	0.008	38.621	218.743	583.314
Total	404				0.605	0.480	2,216.915	21,134.064	56,357.505

Pine Park can be potentially conserved as an urban green space under urban regulation and local people can benefit from fresh air containing as much as 56,357.505 ty^{-1} which is enough to support about 1 902 people in a year: approximately 5 % of the population of the local district. This equates to two trees serving each person.

Thermal discomfort index.

Despite the complexity of issues involved in outdoor thermal comfort, it is necessary to increase our understanding of these issues to provide better guidance in sustainable urban development. This study investigated the effects of the temperature and humidity in order to determine thermal discomfort index and assess the possibility of revitalizing parts of the city and improving the quality of life provided by Pine Park.

Pine trees contribute to the reduction of the thermal discomfort index, a THI (thermal hygrometric index). In the forest interior, the average THI from all sample plots was smaller than was the average THI from the forest exterior, with differences of about 6^oC to 7^oC in the maximum THI value and of 11^oC to 12 ^oC in the minimum THI value. Average THI values in the forest interior were about 25^oC to 26^oC, while those in outside areas were about 32 – 33^oC. These figures are shown in Table 2,

Table 2. THI values (^oC) from both the interior and the exterior of the Park.

Location		Maximum	Mininum	Average +/- stdv
Forest Interior	Station 1	28	18	25 +/- 2
	Station 2	28	21	26 +/- 2
	Station 3	29	21	25 +/- 2
Forest Exterior	North	32	29	31 +/- 1
	South	33	30	32 +/- 1
	East	32	30	31 +/- 1
	West	32	26	31 +/- 1

Average THI values were similar to the maximum and minimum THI values, and exterior park THI values were consistently higher than were the interior values. These values were positively related to the temperature, with change in temperature being directly reflected by fluctuation in THI. This finding also reveals that the interior park temperature is lower than are exterior park temperatures observed by Shashua-Bar and Hoffman (2004) and Yu and Hien (2006) who studied the cooling effect of trees in vegetated areas. Under foliage, the cooling effect reached 1.5 ^oC and 3.5 ^oC in the hot dry city and was about 1.7^oC - 3.3^oC lower than in areas where there were no trees. Thus, the differences of temperature will be expressed on different THI values (Ali-Toudert and Mayer, 2005 and 2007; Taha; 2006).

Generally, THI values were between 23.2 ^oC and 25.6 ºC under windless conditions. Average THI values were less than 26 ºC only in the interior of the Pine Park. According to the references, the value of 26 ºC is critical because below this value, less than 50% of the population feels discomfort, and beyond this value, more than 50% of the population feels discomfort. However, most people in the City of Banjarbaru felt comfort at 28 ºC. In hot humid countries, like Malaysia and Indonesia, most people can accept 22 ^oC to 28 ^oC as the range of comfort. (Unger, 1999; Karyono, 2001; Charalampopoulos, and Chronopoulou-Sereli, 2005).

This finding shows that almost all interior Pine Park sites had values that were either lower than or similar to the critical THI value. Conversely, all of the THI values from the exterior of Pine Park exceeded the critical value. This shows that the vegetation in Pine Park has a beneficial effect in lowering THI, with a cooling effect reaching 6-7 ºC. The average THI of the south site represented the highest value; all of these data were obtained along an asphalt road surrounded by a dense human settlement. The west site was a grass field, while the north and east sites were close to the irrigation channel and surrounded by rice fields. The findings reveal that temperature fluctuation is positively correlated with THI and that THI variation is determined by temperature change. The Pearson coefficient correlation (r) of temperature and THI relation was 0.999 (r-square: 0.998), while the r of temperature was -0.952 (r-square: 0.906). Also, the r of Rh and THI was 0.951 (r-square: 0.904). These figures are comparable to the values provided in the literature and reveal that trees in the forest interior provide a cooling effect that is superior to that at exterior sites, which consist of grass, soil and asphalt and cement ground (Yilmaz et.al., 2008; Thorsson, 2007; Streiling and Matzarakis, 2003)

The volume of greenery has a beneficial influence on the bioclimate of the whole interior of the park. The canopy volume, temperature, Rh and THI of 84 under foliage sites were quantitatively calculated, and the results are shown in Table 3.

Table 3. Canopy volume, temperature, Rh and THI from selected sites

Variabel	Unit	n	Min	Max	Average +/- Std
Canopy volume	m^3	84	12.9	49.8	24.1 +/- 11.1
Temperature	°C	84	23.0	35.0	23.2 +/- 6.4
Humidity relative	%	84	39.5	82.7	52.5 +/- 13.4
THI	°C	84	18.4	28.0	25.0 +/- 6.83

The r values between canopy volume and interior park temperature, canopy volume and THI and canopy volume and humidity were 0.956, 0.956 and 0,886, respectively. This finding suggests that the volume of vegetation volume contributes to the overall cooling effect in the forest environment.

Pine trees are beneficial in lowering air temperatures, in providing shade and in improving thermal comfort. The average temperature in the park interior was 25.2ºC, with a minimum of 23.0ºC; those figures were considerably lower than were those in exterior sites of Pine Park, where the average temperature was generally 32ºC, with a minimum of 30ºC. Similarly, Rh values from the interior of Pine Park value were lower, with an average of 52.5% and a maximum of 82.7% than in the exterior sites, where the average was about 78.5%, with a maximum of 92.4%. The Pine Park was particularly cool (in relative terms) under very hot weather conditions (mean local temperature at 35ºC during the day time), when difference of extreme condition exceeds 7 ºC. This observation supports the idea that the green space plays an important role in mitigating situations of extreme heat. Thus, the findings promote the idea of changing the green space across the different seasons, especially for the purpose of anticipating heat stress effects and, thereby, mitigating such effects for the user and providing greater accessibility to the green space (Andrade and Vieira, 2007; Lafortezza et.al., 2009; Potchter et.al., 2006; Spangenberg et.al., 2008; Nowak, 2000)

IV. Conclusion

Pine Park in the City of Banjarbaru provides ecological benefits, such as carbon storage, balanced carbon, carbon sequestration and oxygen production, which benefit local inhabitants. In addition, trees have other beneficial effects, such as the cooling effect that reduces human thermal discomfort. High and wide-canopy trees have a maximum cooling effect during the day time and have a positive effect on human climatic comfort. Spaces without trees and canopy are warmer than are other places inside the park. The results of this study suggest that the most useful type of urban park in a tropical area, from the climatic point of view, is a park with high and wide-canopied trees. Furthermore, the results suggest that steps should be taken to avoid parks with grass coverage and without trees, and promote the idea that green space in the City of Banjarbaru can be adapted for climate change by providing access to shade. Thus, the existence of Pine Park should be preserved to balance the growth of the built in environment in the City of Banjarbaru.

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