

Compatibility between Microclimate Parameters in the Characterisation and Monitoring of Forest Ecosystem Conditions and Environmental Interactions

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The area of the daily dynamics of the microclimate gradient were formulated by the author in 2012, and have been applied in various studies of mangrove and terrestrial forest ecosystems. This parameter represents the thermal diffusion between the forest ecosystem and the adjacent environment, for one day or one irradiation period. The stages of determining this parameter include other parameters, namely: the maximum edge-interior difference, the maximum edge gradient and the depth of edge effect, which have been used by experts before. This article describes the compatibility between the parameter, the area of the daily dynamic gradient, with three other parameters in the characterisation and monitoring of ecosystem conditions and ecosystem environment interactions. The results of the research on several transects that vary in ecosystem and environmental conditions, are that all four parameters always show high correspondence. The four parameters can be used in an integrated manner in monitoring changes of forest ecosystems. The area of the daily dynamics gradient parameter can be used to map or group transects in mangrove forests, based on the quantity of parameters day and night. The advantage of the area of the daily dynamic gradient parameter is that more stable than the other three parameters. The area of the daily dynamics gradient can also reveal the differences of thermal interactions between mangrove forests with the environment, and between forests on land with the environment.

Key words: *Forest ecosystem, environment, thermal diffusion, microclimate, parameters.*

Introduction

Microclimate is defined as the climatic conditions of an area that is localised as a zone that is different from its surroundings (Chen et al., 1999, Medellu, 2012). Research results prove that microclimate variables are very sensitive to the changes of forest ecosystems and the surrounding environment (Godefroid et al., 2006; Berger et al., 2008, Gradstein, 2008). Changes in the magnitude of microclimate variables throughout the day, are related to the process of thermal diffusion between ecosystems and the environment (Medellu, 2012, 2013). Without geothermal sources, thermal diffusion in nature is controlled by the intensity of solar radiation, the absorption of radiation energy by the atmosphere and the earth's surface. Solar radiation energy absorbed by the earth's surface, increases the temperature of elements or materials on the earth's surface. When the temperature of the object reaches 100°K , the object begins to emit thermal energy (Medellu, 2012; Medellu et al., 2012a). Differences in absorption, storage and thermal emissions by elements on the earth surface, cause the diffusion or flow of thermal energy between one object with another. Differences in absorption and thermal emissions of forest ecosystems and adjacent environment components, cause thermal diffusion through the boundaries of the forest (Medellu, 2012; 2019).

The microclimate variables studied by experts are irradiation intensity, air temperature and humidity (Hennenberg et al., 2008; Medellu, 2012; de Lima et al., 2013). Other variables that are often studied are wind speed, soil temperature, and soil moisture (Davies-Colley et al., 2000, Medellu, 2012; Medellu et al., 2012a). Microclimate variables change temporally following the changes of solar radiation intensity and vary spatially due to local conditions or elements of the earth's surface (Newmark. 2001, Medellu, 2012, de Paula et al, 2016). Spatial variations of microclimate in the forest are influenced by the structure of the forest such as variations in stand height, patches and gaps in the forest, canopy density etc. (Laurance et al. 2007; Pinto et al., 2010; Zulkiflee and Blackburn, 2010; Medellu, et al, 2012.b)

Microclimate parameters describe the quantity of microclimate variables and their changes. The microclimate parameters commonly used are: (1) the maximum difference quantity of microclimate variables between the edge and the interior of the forest, (2) the depth of the edge effect, and (3) the maximum edge gradient. Researchers using parameter the maximum difference of edge-interior were: Spittlehouse et al. (2004); Renaud et al. (2010); Chatterjea (2014). Researchers who use the depth of edge effect parameters were Chatterjea, (2014); Chaplin-Kramer et al. (2015); de Paula et al. (2016). The maximum edge gradient parameter were used by Harper et al. (2005); Vodka and Cizek (2013); Chatterjea (2014). The depth of edge effects can indicate fragmentation or gaps in the forest, or changes in forest structure (Medellu, 2012; Medellu et al., 2012b; Magnago et al., 2015). Edge gradients are associated with the flow of thermal energy between the environment and forest ecosystems (Heithecker

and Halpern, 2007; Chatterjea, 2014). Thermal energy flow through ecosystem boundaries can be associated with semi-permeable membranes (Harper et al, 2005; Naiman and Décamps (1997) in Schmidt et al., 2017).

The depth of the edge effect and the maximum edge gradient differ between transects in the forest ecosystem, due to differences of the intensity of radiation entering through the canopy gap. These parameters also differ in magnitude between transects with different bordering environmental conditions (Medellu, 2012, 2013; Chatterjea, 2014; Kolasa, 2014). The parameter magnitude for the variable of air temperature and humidity show the correspondence between transects in similar ecosystems and environmental conditions (Medellu 2012, 2013). Microclimatic parameters also indicate biotic conditions around the edges (Horak and Rebl, 2012; Vodka and Cizek, 2013). The depth of the edge effect is used for the study of transition zones (Baker et al, 2016; Schmidt et al, 2017). Laurance et al. (2011); Pütz et al. (2014), and Chaplin-Kramer et al. (2015) use the depth of edge effect parameter to estimate carbon stocks in the transition zone. This proves that microclimate parameters can be used to characterise the ecological conditions of forest ecosystems and their interactions with the environment (Renaud and Rebetez, 2009; Medellu, 2012, 2013, 2018). If the measurements of air temperature and humidity are repeated in two consecutive days with the same weather conditions, all three parameters show a fluctuating magnitude.

The bias measurement results for the maximum edge-interior difference parameter is 4.8%, the maximum edge gradient is 4.2%, and the depth of edge effect is 8.3% (Medellu, 2012). In two consecutive measurement days, the magnitude of these parameters is reached at different times. These results indicate that although the forest ecosystem (mangrove), environment, and weather conditions are the same, the magnitude of the three parameters is inexact. The depth of the edge effect sometimes shows a peak magnitude of two to four times a day (Medellu, 2012). Chen et al (1999) found that the peak magnitude of the depth of edge effect occurs four to six times a day. This daily fluctuation is the reason for De Siqueira et al (2004) using the variance data in analysing the depth of edge effect. These results indicate that microclimate parameters can be used to characterise forest ecosystems and adjacent environments (Chen et al, 1999; Medellu, 2012, 2013), but are less valid if used as a reference for monitoring changes of the forest ecosystem and its interaction with the environment. In the analysis of forest ecosystems and their interactions with adjacent environments, it is best to use data range references.

In 2012 the authors published the parameter "area of the daily dynamics of the microclimate gradient " through a dissertation entitled "Mathematical Modelling of the Microclimate Daily Dynamics in the Mangrove Forest". This parameter shows changes in microclimate variables over one day or one irradiation period. The magnitude of this parameter is the cumulative data of the ecosystem and environmental responses to irradiation, as well as interactions

(diffusion of thermal energy) between ecosystems and the environment. The reason for using this parameter is in line with Godefroid et al. (2006) and Laurance et al. (2011) who suggested that the effect of the microclimate in the transition zone is the cumulative response to solar radiation. Since 2012, our team has conducted research on the use of integrated microclimate parameters. This article describes the compatibility between parameters, consistency and the advantage of the fourth parameter: "area of daily dynamics gradient of microclimate".

Method

This section discusses the measurement, analysis and modelling steps carried out in several studies on the application of four microclimate parameters that our team has carried out since 2012. The four parameters are: P1: maximum difference of microclimate variable between the edge and the forest interior, P2: maximum edge gradient, P3: depth of edge effect, and P4: area of daily dynamics of microclimate gradient. These four parameters are related to each other, and they describe the condition of the ecosystem and the interaction of the forest ecosystem with the adjacent environment. The interaction of forest ecosystems with the environment is the process of thermal diffusion through the edge of forest. The author has made an integrated analysis and modelling software for microclimate parameters. The software outputs include parameters P1, P2, P3 and P4. The stages of measurement, analysis, and modelling to determine the microclimate parameters, which have been used, are discussed in detail in the publication of the article (Medellu, 2013, 2018, 2019; Medellu and Tulandi, 2018):

1. Determination of transects and measurement positions, based on observations of ecological variations, and adjacent environments. The measurement position uses a logarithmic distance from the edge. Determination of this distance is based on the assumption of absorption of thermal energy across the forest boundary. The absorption is greater near the boundary or near the source of thermal energy. Higher energy absorption near the forest boundary has an exponential pattern of thermal energy change. For modelling, we need more data near the edge, so that the position near the edge is closer.
2. Measurement. Measurements are made by moving from the edge position to the next position along the transect. The interval for repeated measurements from the edge into the interior of the forest may be one or two hours, to ensure the validity of the modelling results.
3. Tabulate data into the matrices: $T(x, t)$ according to software format (matlab). Each data has a position and time base.
4. Modelling temporal functions. At this stage, temporal functions are generated according to the measurement position along the transect (Figure-1). This analysis-modelling stage produces parameter P1. The temporal function is in the form of a sinusoidal function

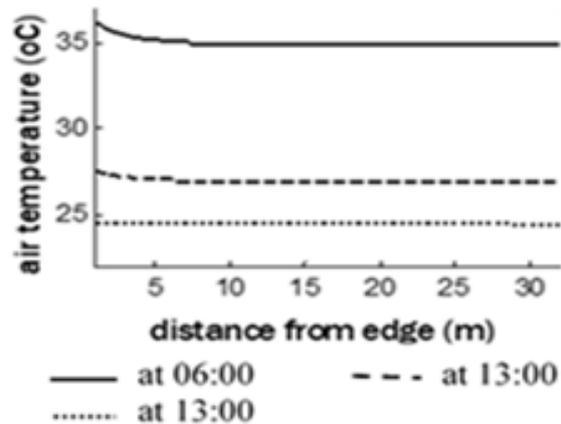
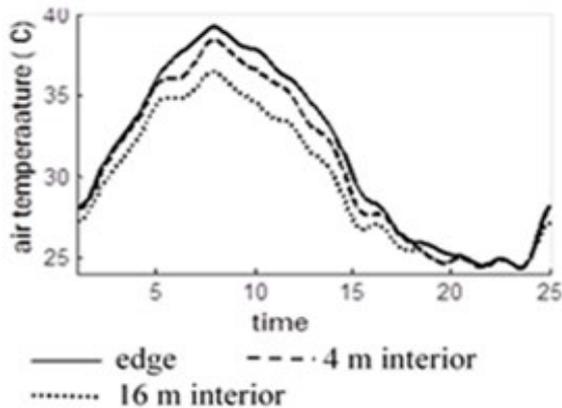
derived from a steady-flow thermal diffusion equation. The general form of the temporal function is

$$T(t) = T_o + \sum_{m=1}^{N/2} a_m \cos \omega_m t + b_m \sin \omega_m t \dots\dots\dots (1)$$

Where T_o is the daily mean of the microclimate variable, $\omega_m = 2\pi m / N$, m is the number of harmonics, N is the amount of data, a_m and b_m are the Fourier coefficients.

5. Data synchronisation. This stage is needed for modelling spatial functions that require the same time base. Difference in measurement time between positions causes the measured data to not have the same time base. This data synchronisation uses a temporal function that was generated in step-4
6. Modelling spatial functions, which describe changes in microclimate variables from the edge to the forest interior. Examples of graphs of spatial functions are shown in Figure-2.

Figure 1. Temporal function of air temperature. Transect 1. Forest of Kahakitang Island
Figure 2. Spatial function of air temperature. Transect 1. Forest of Kahakitang Island



The general form of spatial function is:

$$T(x) = k_1 + k_2 \cdot \exp(k_3 - k_4 \cdot x) \dots\dots\dots (2)$$

Spatial constants and coefficients are generated through an iteration process, with input data of at least three data pairs (x, T). This stage produces the maximum edge gradient (P2) and the depth of edge effect (P3). The P2 parameter is obtained by differentiating the spatial function for position $x = 0$, or $G(t) = dT(x)/dx$, for $x = 0$ or $G(t) = -k_2 \cdot k_4 \cdot \exp(k_3)$. Edge gradient change throughout the day. The P3 parameter is obtained by differentiating the spatial function $dT(x)/dx = 0$, and the computer does iteration to get the value.

7. Determination of the edge gradient magnitude for each time interval that we want. The edge gradient magnitude is used for modelling the daily dynamics of the microclimate gradient function
8. Modelling the daily dynamics of the microclimatic gradient function, using the same mechanism as temporal function modelling (point-4). Through the stages, P4 magnitude are obtained. Other data also obtained are the time of occurrence and the duration of thermal equilibrium between the forest ecosystem and the environment. The area of the gradient dynamics is determined using numerical integrals: $A = \sum_{i=t_1}^{t_2} G_i \cdot \Delta t$. Δt is the sampling time interval. Examples of graphs of daily dynamics gradient functions are shown in Figure-3 and Figure-4.

Evaluation of the compatibility between parameters P1, P2, P3 with P4 is based on the the corresponding magnitude of these parameters from several transects for each microclimate variable. The article also presents the advantage of the fourth parameter in transect grouping, and to distinguish the difference of thermal ininteraction between environment with the mangrove forest and with the forest on land.

Figure 3. Daily dynamic gradient of air temperature. Transect 1. Forest of Kahakitang Island

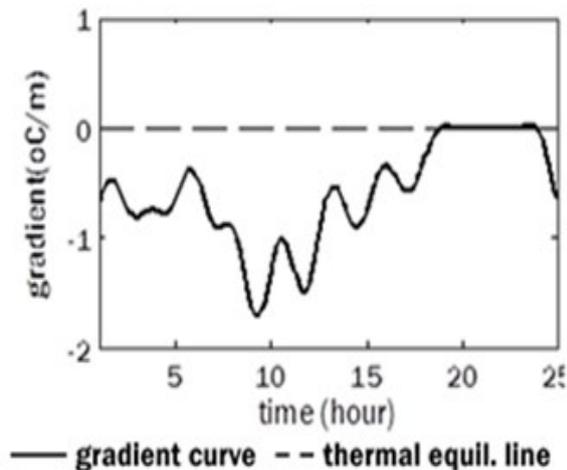
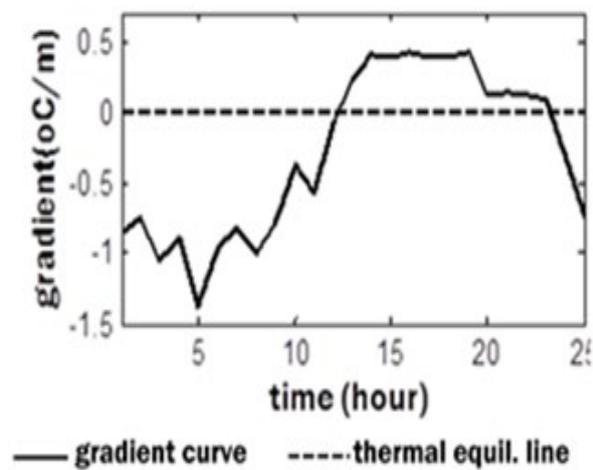


Figure 4. Daily dynamic gradient of air temperature. Transect 1. Mangrove. Arakan village



Results

This section presents the results of analysis and modelling on ten transects, and compares the magnitude of parameters P1, P2 and P3, with P4. This comparison can show the compatibility between the three parameters with the P4. Here also discussed some of the application parameters for the characterisation and monitoring of the condition of forest ecosystems and their interactions with the adjacent environment.

1. Compatibility between parameters for microclimate variables in mangrove forests. For each transect we examine, we measure and analyse to get the microclimate parameter data. The compatibility of three parameters with the P4 was analysed based on the parameter magnitude for ten transects in the mangrove forest. Examples of the result of analysis and modelling of the fourth parameters were presented in Table-1. This data was generated from measurements carried out in 2011. Some of the data has been published through a dissertation (Medellu, 2012), and articles (Medellu, 2013).

Table1: Magnitude of parameter P1, P2, P3, and P4 of air temperature in mangrove forest

Transect Num	Ecotype and mangrove structure	Canopy cover (%)	Adjacent environment	Quantity of parameters				
				P1 (°C)	P2 (°C/m)	P3 (m)	P4 (°C.hour/m)	
							day	night
1	Fringe: homogeny, <i>Rhizophora</i> , gap at 68 m from edge	72-85	Sea	3.6	3	34	9.59	3.04
2	Fringe, homogeny, <i>Rhizophora</i>	75-85	Sea	3.7	3.8	38	9.70	3.14
3	Riverine, homogeny, <i>Rhizophora</i>	78-88	River	4	4	45	9.97	3.07
4	Hammock, fragmented (12 m from the edge)	90-95 55-70	Asphalt street	3.2	2.9	32	8.99	2.84
5	Fringe, homogeny, <i>Rhizophora</i>	75-80	Coast (shrub)	3.4	3	36	9.40	3.14
6	Basin, heterogeny in type	40-65	Coast.shrub	2.8	2.4	27	7.83	2.71
7	Basin, heterogeny, domination of <i>Avicenia</i>	35-55	Coast,shrub	2.4	2.4	27	7.31	2.74
8	Scrub, heterogeny, domination of <i>Avicenia</i>	50-60	Coast,shrub	2.4	2.5	29	7.44	2.55
9	Fringe, homogeny, <i>Rhizophora</i> ,	75-85	Sea	3.7	3.7	42	9.69	3.17
10	Basin, heterogeny, in type	55-65	Coast, rarely high trees	2.6	2.6	39	8.66	2.72

This article presents the results of the analysis of the compatibility between parameters, which have not been analysed before. Table-1 presents data of P1, P2, P3, and P4 for variable air temperatures under the mangrove canopy. Data P1, P2, and P3 presented in Table-1, are the highest magnitude in one day. In fact, for one day there were two to four high magnitude of P1, P2, and P3. Repeated measurements carried out at the next day, showed changes in the magnitude and time achieved. This shows that the parameters P1, P2, and P3 are less stable for the characterisation of the microclimate of the forest. The study also produced parameter data for humidity and water temperature variables.

Compatibility between of parameters: P1 to P4, P2 to P4, and P3 to P4, for the variable of air temperature, humidity, and water temperature, are presented in Figure-5, Figure-6, and Figure-7.

Figure 5. Compatibility of parameter: P1 and P4

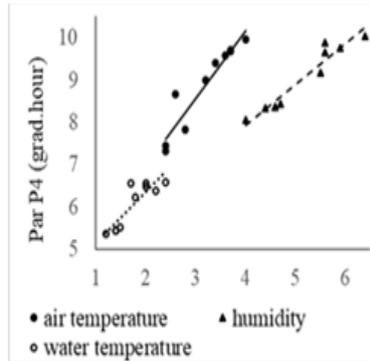


Figure 6. Compatibility of parameter: P2 and P4

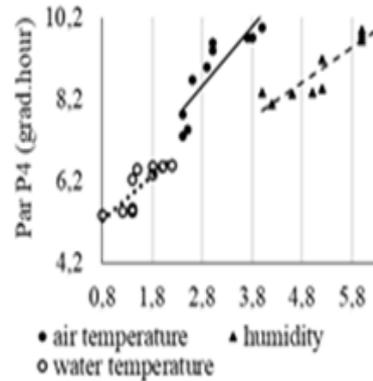
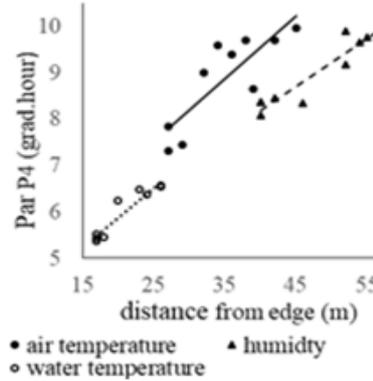


Figure 7. Compatibility of parameter: P3 and P4



The vertical axis or ordinate of Figure-5 through to Figure 7 is the P4 magnitude that has a unit: gradient.four. Gradient units differ between microclimate variables. For air temperature and water temperature, the gradient unit is $^{\circ}\text{C}/\text{m}$. For humidity, the gradient unit is $\%/ \text{m}$. For Figure-5, the abscissa unit, is a microclimate variable unit. For Figure-2, the abscissa unit is a gradient unit, i.e. $^{\circ}\text{C}/\text{m}$ for air temperature and water temperature, and $\%/ \text{m}$ for humidity. The abscissa unit of Figure-7 is meter. The abscissa in Figure-7 states the distance from the edge to the forest interior.

Figure-5, Figure-6, and Figure-7 each show a linear trend of correspondence between P1 and P4, P2 with P4, and P3 with P4, for variable temperatures, humidity and water temperature. Test of data compatibility between the parameters P1, P2, and P3 with P4, can adopt the Root Mean Square Deviation (RMSD) test, between the P4 data generated by the computer, and the data obtained from the regression function as a model data. Model data is obtained by inputting data P1, or P2, or P3 into the model function (linear function). The level of parameter compatibility, for example between P1 and P4, is indicated by the RMSD value. The smaller RMSD value indicates the high level of compatibility.

In the compatibility test of P1 with P4, the RMSD value of air temperature is 0.352, humidity is 0.255, and water temperature is 0.324. Compatibility between P2 and P4, indicated by the RMSD value of air temperature is 0.452, humidity is 0.2279, and water temperature is: 0.385. In the P3 and P4 compatibility test, the RMSD value of air temperature is 0.386, humidity is 0.305, and water temperature is: 0.316. Physically, the level of compatibility of these parameters is high, because they both represent the thermal conditions of the ecosystem and the process of thermal diffusion between the environment and the ecosystem. The results of

this test, indicate that the parameters P1, P2, P3, and P4 for variables: air temperature, humidity, and water temperature can be used to characterise mangrove ecosystems and their interactions with the environment.

2. Compatibility between microclimate parameters for forest characterisation. Table-2 presents microclimate parameter data on two transects in the forest on the mainland of Kahakitang Island, Sangahe District. Measurements were conducted in 2018. When compared, the quantity of parameters P1, P2, P3, and P4 on transect-1, is greater than that of transect-2. These results indicate that these parameters correspond to one another and can characterise forests on land, which are bordered by different environments. The environment bordering the forest area on transect-1 is a dense settlement. The environment bordering the forest where transect-2 is chosen is a plantation area. The thermal energy in the residential environment is higher than in the plantation area.

The interesting thing from the data of gradient dynamics area in Table-2 is the area of night gradient, which has zero value. This applies to transects-1 and transect-2. This shows that there is no thermal source in the forest. Thermal energy entering under the canopy comes from horizontal diffusion, and the penetration of solar radiation through the canopy gap. When the sun sinks, the thermal energy in the forest decreases following the decrease of thermal energy in the open environment. At a certain time, a thermal equilibrium is reached, which lasts until the forest and environment get sun radiation again. This is different from the mangrove ecosystem which receives a supply of thermal energy from the mass of warm sea water, so that at night the air temperature under the mangrove canopy is higher than the environment (Medellu, 2012, 2013, 2019). Differences in temperature gradient dynamics under the on land forest canopy and under the mangrove canopy are shown in Figure-3, and Figure-4. This proves that parameter P4 can reveal differences in thermal interactions between the environment and mangrove forests and between the environment and forests on land.

Table 2: Analysis of microclimate parameters from two transects in the forest ecosystem on Kahakitang Island, Sangihe Regency.

Transect	Microclimate parameter	Microclimate variables					
		Air temperature		humidity		Water temperature	
		quantity	unit	quantity	unit	quantity	unit
1	Maximum quantity at the edge	37.9	°C	89.4	%	29.4	°C
	Max.difference edge-interior (P1)	3.4	°C	7.2	%	4.4	°C
	Maximum edge gradient (P2)	-1.8	°C/m	-2.7	%/m	-0.4	°C/m
	The depth of edge effect (P3)	26	m	25.4	m	10.5	m
	Duration of thermal equilibrium	5.8	hour	7.8	hour	8.2	hour
	The area of gradient dynamic (P4) (at the day)	14.46	°C.hour/m	18.24	%.hour/m	7.42	°C.hour/m
	The area of gradient dynamic (P4) (at night)	0	°C.hour/m	0	%.hour/m	0	°C.hour/m
2	Maximum quantity at the edge	35.4	°C	92.6	%	27.7	°C
	Max.difference edge-interior (P1)	2.2	°C	4.8	%	2.4	°C
	Maximum edge gradient (P2)	-0.8	°C/m	-0.9	%/m	-0.3	°C/m
	The depth of edge effect (P3)	14.4	m	15.2	m	8.8	m
	Duration of thermal equilibrium	8.4	hour	8.7	hour	9.5	hour
	The area of gradient dynamic (P4) (at the day)	6.8	°C.hour/m	8.22	%.hour/m	4.86	°C.hour/m
	The area of gradient dynamic (P4) (at night)	0	°C.hour/m	0	%.hour/m	0	°C.hour/m

3. Transect grouping based on the magnitude of the parameter P4, for air temperature and humidity. The results of the analysis and modelling of the area of daily dynamics gradient for air temperature and humidity under the mangrove canopy can be used for mapping or grouping of transects. Figure-8 shows the grouping of transects based on daytime air temperature and humidity data. Figure-9 shows the grouping of transects at night.

Figure 8. Transect grouping based on the area of gradient dynamic of air temperature vs humidity on the day (Medellu, 2013)

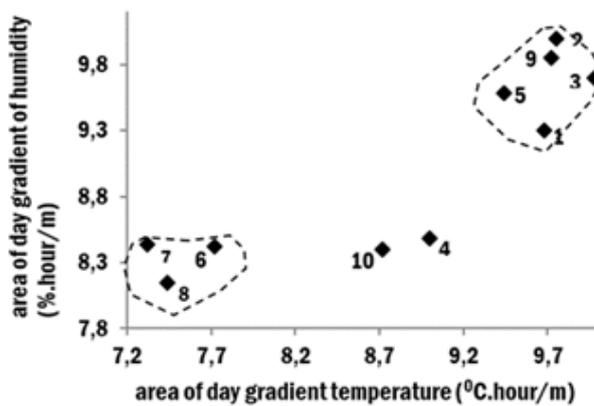
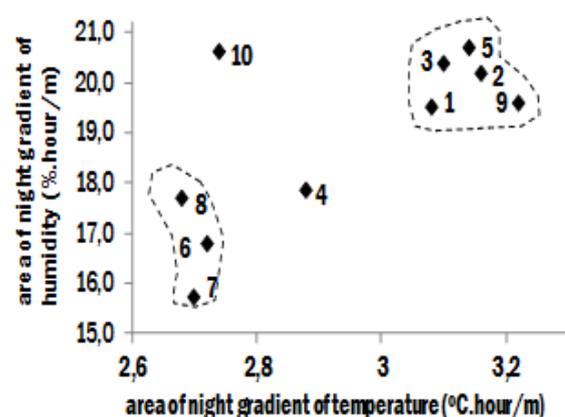


Figure 9. Transect grouping based on the area of gradient dynamic of air temperature vs humidity at night (Medellu, 2013)

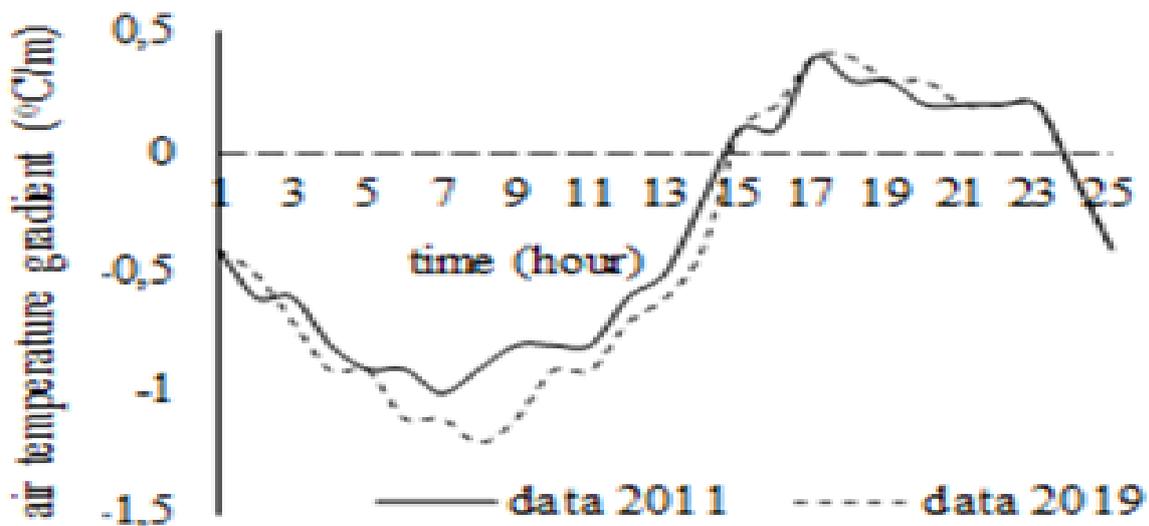


The consistency of transect groupings based on parameter P4 shows that this parameter can be used as a reference for monitoring ecosystem conditions and environmental influences. If there is a change in the ecosystem or environment, transects will change position in the grouping. This analysis cannot be carried out using the other three parameters. The magnitude of parameters P1, P2, and P3 day and night, do not form the same transect grouping.

3. Monitoring changes in the size of gaps in mangrove forests

Figure-10 shows two daily dynamics graphs of temperature gradients along transects in a mangrove forest in Talengen Bay. The graph shows the results of measurements at different times. In this transect we have carried out three measurements, namely on May 8-9, 2011, July 20-21, 2016 and December 18-19, 2019. The graphs displayed are the results of the first and third measurements. The results of the second measurement are not displayed. Weather conditions, the same for three measurements, is not raining but not in the dry season.

Figure 10. Air temperature gradient dynamic of transect 1. In mangrove forest, Talengen Bay



Measurements were made in the same time frame, which starts at 07:00 until 07:00 the next day. At this location there is a gap that is used as a community boat lane. Since 2008 this boat track has not been used anymore and mangrove forests are growing, narrowing this gap. Changes in the gap size and the results of the analysis of the P1, P2, P3 and P4 parameters for air temperature are presented in Table-3

Table 3: Gap conditions in mangrove forests and quantity of microclimate parameters

Year	Mangrove width (m)	Gap width (m)	Canopy cover (%)	Quantity of microclimate parameters				
				P1 (°C)	P2 (°C/m)	P3 (m)	P4 (°C.hour/m)	
							day	night
2011	68	30	72 %-85 %	3.2	4.6	31	9.586	3.034
2016	76	18	75 %-86 %	3.6	4.9	34	9.982	3.424
2019	79	15	74%-87 %	3.8	4.9	35	9.998	3.446

The results of the analysis to determine the quantities of P1, P2, and P3, once again show several quantities that are almost the same in a day. Data P1, P2, and P3 shown in Table-2 are the highest quantities in one day. The data in Table-3 shows the increasing of the quantity of parameters were corresponding to the increasing of mangrove width or the reduction of gap size. For almost the same percentage of canopy cover, it can be interpreted that changes of the quantity of microclimate parameters are related to the changes of the size of gaps in the mangrove forests. These results are in line with the results of study by Asbjornsen et al. (2004), De Siqueira et al. (2004), Fletcher (2005), Laurance et al, 2007; Morrissey et al. (2007) and Gradstein (2008), which use the parameters P1, P2, and P3. Research by Zulkiflee and Blackburn (2010) concluded that the presence of gaps in the forest, affected the depth of the edge effect. The data shows that the depth of the edge effect increases with the reduction in the width of the gap. The existence of a gap causes thermal diffusion from two directions, i.e. from the gap and from the open sea. This two-way thermal diffusion causes the quantity of parameters P1, P2, P3 and P4 to be lower when the gap is wide. Matching magnitudes between parameters concludes that these parameters can be used to monitor changes in the structure of mangrove forests.

Conclusion

The results of research on several transects in mangrove forests and forests on land, showed the microclimate parameter, namely: the maximum difference of the edge-interior, the maximum edge gradient, the depth of edge effects, and the area of daily dynamics gradient were high in correspondence with each other. The results of compatibility tests between parameter, the area of daily dynamic gradient, with the three parameters that have been used by experts before, prove that this fourth parameter can be used for characterisation and monitoring of forest ecosystems and their interactions with the environment. The parameter, the area of the daily dynamics gradient of the microclimate, has an advantage over the other three parameters. In addition to the more stable quantity, this parameter can be used for grouping transects, and monitoring changes in ecosystems, including changes in the size of gaps in the forest. The area of the daily dynamics gradient of the microclimate can show the difference in thermal diffusion between the environment and the forest on land, and between the environment and mangrove forest. Characterisation and monitoring of changes in forest ecosystems and adjacent environments: it is better to use the fourth parameter that represents



the thermal interaction between the forest and the environment for one day. In characterising forest ecosystems using the other three parameters, data range should be used, according to the quantity variations identified during the irradiation period.

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