The Plane Area of Daily Dynamics of Microclimate Gradient Concepts, Methods and Application Results

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Abstract

Parameter the plane area of daily dynamics of microclimate gradients is the plane area surrounded by the curve of daily dynamic of microclimate gradients with the thermal equilibrium lines. This parameter shows the thermal interaction of forest ecosystems with the environment. This interaction is the process of thermal diffusion through the boundary plane, in the horizontal direction. Mathematical analysis and modeling for the determination of function and plane area of the daily dynamics of the micro-climate gradient include the stages with the output of other micro-climate parameters that are commonly used before. Variations of ecosystem conditions and adjacent environments have different magnitudes in gradient dynamics. The results of the study show that this parameter has a more stable magnitude than the other microclimate parameters. Changes or variations in the quantity of this parameter can also detect the influence of weather, the existence of gap or hole, detect patches in the structure of the forest. Current development shows that this parameter can also characterize the vertical interaction between air and water and air with soil.

Introduction

Microclimate is an interesting issue related to weather changes and the emergence of extreme weather, changes in environmental comfort etc. The microclimate variables studied by experts include: (1) radiation intensity, (2) air and soil temperature, (3) air humidity, (4) wind speed (Davies_ Colley et al., 2000, Newmark, 2001; Hennenberg et al, 2008, de Lima et al., 2013). The microclimate quantity is expressed by the magnitude of parameters: the maximum difference inside and outside the forest, the depth of the edge effect as the farthest distance is affected by environment, the maximum edge gradient (Gehlhausen et al. 2000; Stewart and Mallik, 2006; Medellu et al., 2012; Ibanez et al., 2012) The magnitude of these parameters varies throughout the day, due to changes in the intensity of the sun radiation. In fact, the magnitude and time of reaching these parameters are significantly different for each transect, even though measurements are made in the same weather conditions. These parameters cannot show ecosystem capacity in controlling the total daily thermal diffusion between ecosystems and the environment. These parameters do not provide a relatively fixed magnitude to characterize forest ecosystems and their interactions with the environment.

In 2012, the authors formulated new parameters, namely the plane area of daily dynamics of microclimate gradient. The plane area of the daily dynamic gradient is the area surrounded by the curve of daily dynamics of microclimate gradient with the thermal equilibrium line between forest ecosystems and environment. Daily dynamics gradient curves are curves generated from edge gradient data which varies according to time. This curve is plotted on the plane (t, G (t)) where t is time and G (t) is the magnitude of the edge gradient. The thermal equilibrium line is a line that has an edge gradient value = 0 which is plotted in the same plane. Gradient edges are the magnitude of the gradient at the boundary of the ecosystem with the environment. This paper describes the concept, method and the results of application of this parameter.

Concept and Method

The function and magnitude of daily dynamic gradient are determined through the stages of mathematical formulation of the thermal diffusion model:

$$\frac{\partial \boldsymbol{u_i}}{\partial \boldsymbol{t}} = \boldsymbol{\nabla}.\,\mathrm{D}(\mathbf{x})\boldsymbol{\nabla}\mathrm{u_i} + \mathrm{f}\,(\mathbf{x}, \mathbf{u}) \quad \ldots\ldots(1)$$

where u is a microclimate variable, x is distance and t is time. The above equation has a component of space and time. For environmental conditions that can be considered homogeneous, the above equation can be formulated in form (Bellomo et al., 2007):

$$\frac{\partial u}{\partial t} = \mathrm{k}\nabla^2\mathrm{u} \quad \ldots\ldots(2)$$

$\partial u / \partial t$ is the thermal diffusion rate, u is the thermal quantity and k is the diffusion coefficient. To analyze the thermal interactions between forest ecosystems and the environment, a horizontal direction measurement transect is chosen perpendicular to the edge or boundary of the ecosystem with the environment. Equation (2) can be expressed as a one-dimensional equation:

$$\frac{\partial u}{\partial t} = k_0 \frac{\partial^2 u}{\partial x^2} \qquad (3)$$

Mathematical models for one-dimensional thermal diffusion can be applied with the assumption: (1) there is no variation in the magnitude of the microclimate variable in parallel to edge and in vertical direction, (2) the flow of energy from the environment into the forest and vice versa is steady. From the research experience, the thermal energy flow can be assumed to be steady if measurements are made at wind speeds of less than 2 m/s. Possible analytic solutions for equation (3) are:

$$u(x,t) = e^{-k^2\alpha^2 t} \sin k x \qquad (4a)$$

or ..

$$u(x,t) = e^{-k^2\alpha^2 t} \cos k x \qquad (4b)$$

α is a thermal diffusion coefficient, k is a constant whose sign can be positive or negative.

The stages of determining the function and magnitude of the area of daily dynamics gradient are as follows:

1. Determination of transects and measurement positions.

   Transects are determined according to environmental variations, the condition of forest ecosystems and are in accordance with the purpose of measuring or obtaining information. To describe a forest ecosystem, several transects can be taken according to variations in the adjacent environment such as the open sea, trees, land with or without cover, asphalt roads etc. Forest structure variations, for example, are homogeneous or not homogeneous, the presence of gaps, patches, variations in the density of the canopy etc. must also be considered in determining the transect. The measurement position using logarithmic distance, closer to the edge and more tenuous with increasing the distance from the edge. Determination of this position is based on consideration of the thermal absorption that greater near the edge. These considerations also determine the validity of a series of functions: temporal - spatial - gradient dynamics.
2. Set the time interval for repeating measurements at each position, for example 1 hour. For measurements that are not synchronized between positions, the difference in measurement time must be recorded and entered for correction and data synchronization.
3. Enter measurement data in position-time format, and compile data matrix u (x, t) to be included in the software "micro climate parameter analysis and modeling".
4. Mathematical modeling of temporal functions by separating position dan time components of equation (4). The temporal function for each measurement position is:

$$T(t) = To + \sum_{m=1}^{N/2} a_m \cos \omega_m t + b_m \sin \omega_m t \qquad (5)$$

where

and

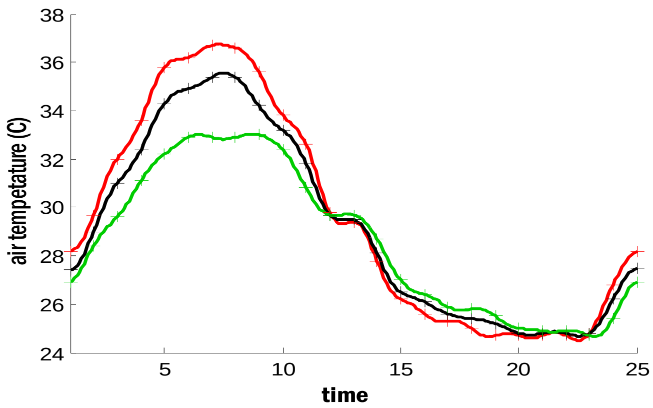
$$a_m = \frac{2}{N} \sum_{t=0}^{N-1} f(t) \cos \omega_m t \qquad (6a)$$

$$b_m = \frac{2}{N} \sum_{t=0}^{N-1} f(t) \sin \omega_m t \qquad (6b)$$

$\omega_m = 2\pi m/N$, m is the number of harmonics, a_m and b_m are Fourier coefficients. T_0 is the average daily data of microclimate variables in the selected position, m is the harmonic count, and N is the number of data pairs (t, T (t)). N/2 is the number of sinusoidal terms of the Fourier function formed from pairs of data (t, T (t)). The stages of modeling Fourier functions are:

1) Determine the a_m and b_m coefficients, using equations (6a) and (6b).
2) Determine the coefficient of $c_m^2 = a_m^2 + b_m^2$.
3) Determining the contribution of diversity: $s_m = (c_m^2/(2.\sigma)).100$
   σ is the standard balance of micro climate variable data.

Through this stage a continuous temporal function is produced, where we can obtain any T data for each selected time t. Temporal functions are Fourier functions. Each measurement position or position we choose along the transect has its own temporal function. Figure 1 presents the temporal function of the air temperature under the mangrove ecosystem for positions 1 m, 8 m and 32 m from the edge



Measurements performed starting at 7 a.m (corresponding to abscissa 0) on May 30 to 7 a.m on May 31, 2017 (abscissa 24). This temporal function produces a parameter: the maximum difference of microclimate variables between the edges and the forest interior, the time to reach the maximum difference and the time of the occurrence of thermal equilibrium. Figure 1 shows that during the day between 07.00 and around 18.00 the air temperature at the edge is higher than at 8 m and 32 m from the edge.At night around 7:00 p.m. until morning around 4:00, the air temperature in the mangrove forest is slightly higher than the edge and environment. The density of canopy of mangrove forest on transect-2 ranges from 80% - 86%. This dense canopy caused the low direct penetration of sun radiation so that the air temperature is lower than the open environment. The air temperature under the canopy is controlled by the horizontal diffusion from the environment into the forest. At night, the air temperature below the canopy decreases more slowly than in the open sea environment. At night, the air temperature below the canopy is also influenced by sea water which has a high temperature than the air

5. Synchronization of data

Data synchronization needs for measurements between positions that are not synchronous. The difference in measurement time between positions is substituted into the temporal function (5) to produse the new T (t) which is synchronized. If measurements are taken simultaneously, this step is not carried out

6. Determination of spatial functions

The spacial component of equation (4) is generally formulated as

$$y = f(x) = k_1 + k_2.\exp(k_3 - k_4.x) \quad \ldots\ldots (7)$$

where x is the distance from the edge. The application of equation (7) is only valid if the data between positions are synchronous. To determine the constants k_1, k_2, k_3 and k_4 usually needs four pairs of data. Computer iteration techniques make it easy to determine these constants and coefficients, using only three pairs of data, provided that one of the data is a reference point data that has a value of x = 0. For three data pairs (0, y_0), (x_1, y_1), and (x_2, y_2), the equation produced is:

$$(y_0\text{-}y_1)/(y_0\text{-}y_2)=[(\exp(k_4.x_2).(\exp k_4.x_1\text{-}1)]/[(\exp(k_4.x_1).\exp(k_4.x_2\text{-}1)] \quad \ldots\ldots (8a)$$

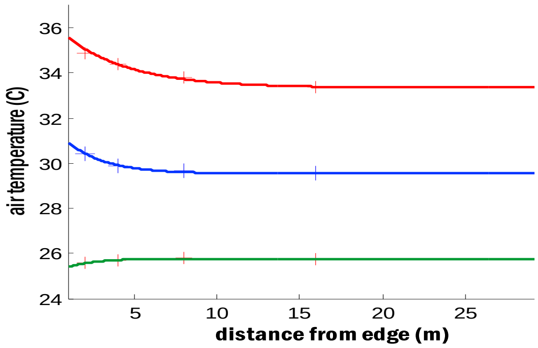
$$k_3 = (y_0 - y_1)/(1\text{-}1/\exp(k_4.x_1)) \quad \ldots\ldots (8b)$$

$$k_2 = (y_0 - y_1)/(\exp(k_3) - \exp(k_3 - k_4.x_1)) \quad \ldots\ldots (8c)$$

$$k_1 = y_0 - k_2.\exp(k_3) \quad \ldots\ldots (8d)$$

Iteration is done by changing the value of k_4 followed by k_3, k_2, and finally k_1. In each iteration cycle, the computer calculates the value of y (microclimate data) for each position (x); and compare it with measurement data. The average deviation between model to measure data is used as an iterative controller. The iteration is stopped at the smallest deviation value. The spatial function changes throughout the day as shown in Figure-2. The spatial function graph shows that the air temperature at 13.00 is higher than the air temperature at 09.00 and 01.00.

Temperature gradients at 13.00 and 09.00 indicate that at 09.00 and 13.00 the environment has a higher temperature than the interior of the forest. At 1:00 o'clock the temperature in the forest is slightly higher than the ambient air temperature.



Spatial function and the bias of model to measured data of each graph are:
At 09.00: t (x) = 29.54 + 0.25.exp (2.14 - 0.43 x) with a bias of 0.03
At 13.00: t (x) = 33.35 + 0.17.exp (2.84 - 0.25 x) with a bias of 0.11
At 01.00: t (x) = 25.77 - 1.28.exp (-0.66 - 0.59.x) with a bias of 0.01

This spatial function can produce thw dwpth of edge effect parameters, namely the farthest distance of the thermal environment influence into the forest. The edge effect is obtained by differentiating the spatial function to distance x: d (f (x)) / dx = 0. The distance x corresponding to this value is called the edge effect. Distance of edge influence changes throughout the day. Edge effect data used to characterize ecosystems is the longest distance on one day. Edge effects data are important in the analysis of the presence and movement of aquatic biota around mangrove forests.

7. Determine the edge gradient

Edge gradient are the magnitude of the gradient of spatial functions at the edges or at the boundaries of forest ecosystems and the environment. Edge gradient change throughout the day which shows the difference in thermal energy between the environment and the ecosystem. Edge gradient is obtained by differentiating the spatial function f (x) to x and then entering the value x = 0 to obtain a certain value

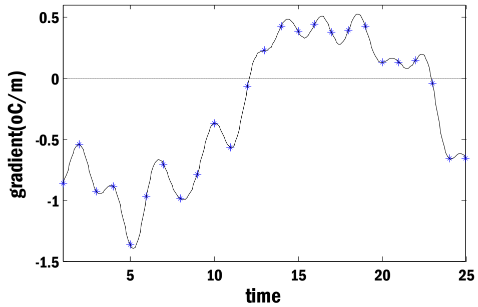
$G_0 = - k_2.k_4.\exp(k_3)$ ……………………………………………………….(9)

The gradient magnitude of the edges changes throughout the day following changes in spatial functions or the value of k2, k3, and k4. The changes of edge gradients throughout the day are sinusoidal, similar to the temporal function of microclimate variables.

8. Determine the function and plane area of daily dynamics of microclimate gradients

Using the same procedure as determining temporal functions, a graph of gradient dynamics functions is generated such as Figure-3. Figure-3 presents a graph of the gradient function of transect-2, of Talengen Bay, Sangihe District, North Sulawesi Province. The dotted line shows the thermal equilibrium condition between the environment and the mangrove forest ecosystem, which the air temperature gradient has a zero value.Curves located below the thermal equilibrium line show a negative gradient, where the environment has a higher temperature than the ecosystem. In this conditions, the thermal energy flows from the environment into the forest. The curve above the thermal equilibrium line shows that the temperature in the forest is higher than the environment and thermal energy flows from the forest to the environment

Figure-3. Graphic of air temperature gradient of transect-2, Talengen Bay



The function of the daily dynamics of air temperature gradient of transect-2 at Talengen bay is:

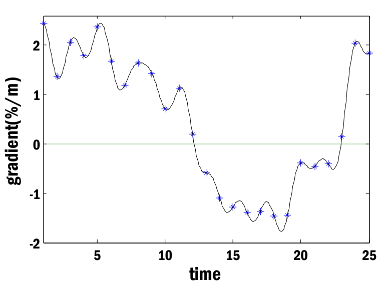
Gt(2) = -0.2944 -0.2822*COS((2πt/180)/24) -0.7046* SIN((2πt/180)/24)+ 0.0246*COS((4πt/180)/ 24)+ 0.0455* SIN((4πt/180)/24) -0.0479* COS((6πt/180)/24) -0.0306* SIN((6πt/180)/24) -0.0440* COS((8πt/180)/24)+ 0.0658* SIN((8πt/180)/24) -0.0937* COS((10πt/180)/ 24)+0.0001* SIN((10πt/180)/24) -0.0812* COS((12πt/180)/24)+ 0.0189* SIN((12πt/180)/ 24) +0.0163* COS((14πt/180)/24) -0.0278* SIN((14πt/180)/24)+ 0.0649* COS((16πt/180)/ 24)+ 0.0734* SIN((16πt/180)/24) -0.0478* COS((18πt/180)/24) -0.0040* SIN((18πt/180)/ 24)+ 0.0099* COS((20πt/180)/24) -0.0577* SIN((20πt/180)/24)+ 0.0359* COS((22πt/180)/ 24)+0.0021* SIN((22πt/180)/24)+ 0.0808* COS((24πt/180)/24) -0.0402* SIN((24πt/180)/ 24)

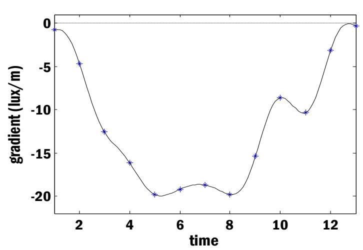
The plane area of daily dynamics of microclimate gradients is determined using numerical integrals:

$$A = \sum_{i=t_1}^{t_2} G_i . \Delta t \text{ ....(10)}$$

where Δt is the interval of the time sampling and G_i is the gradient value of enumerator i. The magnitudes of t_1 and t_2 indicate the time of occurrence of the first and second thermal equilibrium between the forest ecosystem and the environment. The plane area of gradient dynamics during the day is the area of the plane bounded by the thermal equilibrium line with the curve below.The plane area above the thermal equiibrium line is nighttime gradient area. The unit of plane area of dynamics gradients is the unit of variable times the unit of time, divided by units of distance. For temperature, the unit is ^{0}C.hours /m. The gradient dynamics index is the plane area of night gradient divided by the plane area of daytime gradient. The gradient dynamics index has no units The plane area of air temperature gradient of transect-2 at Talengen Bay is 9.696 ^{0}C.hours/m at the day and 3.140 ^{0}C.hours/m at night. The gradient dynamics index is 0.324. (Medellu, 2012; 2013). The magnitude of the plane area of the daily dynamics of air temperature gradient is relatively constant for each transect if the measurements are carried out in the same weather conditions and the wind speed is less than 2 m/s.

The functions of daily dynamics of air humidity gradient, light intensity, and water temperature of transect-2 in the mangrove ecosystem in Talengen Bay are presented in Figures 4, 5 and 6 respectively.





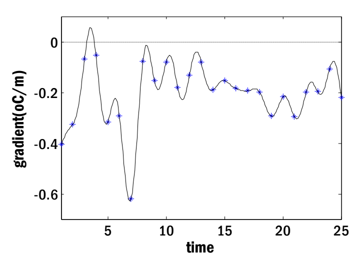


Figure-4. Graphic of air humidity gradient of transect-2, Talengen Bay (Medellu

The plane area of air humidity gradient of transect-2, in Talengen Bay was: 20.013 %.hours/m at the day and 10.028 %.hours/m at night. Index of air humidity gradient was 0.501. The plane area of light intensity gradient of transect-2 in Talengen Bay was 148.711lux.hours/m. Light intensity gradient graph was steeper than the gradient graph of air temperature and humidity. Software output shows the plane area of water temperature gradient as 4.903^{0}C.hours/m at the day and 0.024^{0}C.hours/m at night, with the index of gradient dynamic 0.005 (Medellu, 2013, Medellu and Tulandi, 2018). The curves in Figures 3, 4, 5 and 6 are characteristic of transects. For different transects, the curve and the plane area of the gradient dynamics are different.

The results of the application of plane area of daily dynamic of microclimate gradient

1. Comparison of functions and plane area of dynamic gradient between two transects in the different environment

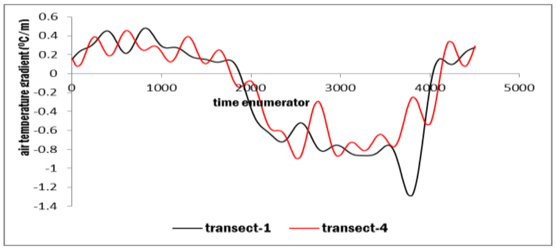
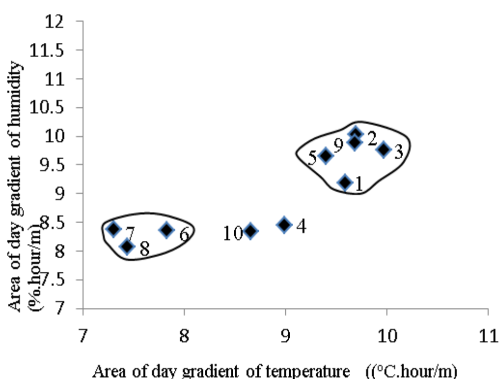
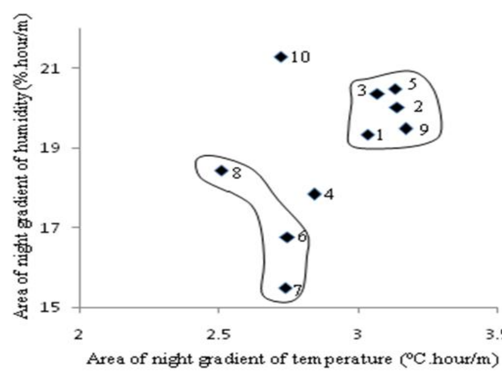


Figure 5 shows the air temperature gradient curves of two different transects, located at the Ratatotok Beach, District of Southeast Minahasa, North Sulawesi Province. Transek-1 is a Rhizopora type mangrove area with a canopy density of 80% - 82%. At a distance of 12 m from the edge there is fragmentation overgrown with various types of mangroves. This mangrove forest borders the asphalt road which is 10 m wide. The plane area of air temperature gradient dynamics at the day is 9,24^{0}C.hours/m and 3.064 ^{0}C.hours/m at night. Transect-4 is heterogeneous overgrown with several types of mangroves dominated by Avicenia with canopy cover 65% - 72%. The plane area at the day is 6.05^{0}C.hours/m and at night 2.024^{0}C.hours/m. This result to prove that the main factor to influence the difference between transect are the adjacent environment and canopy density. The open adjacent environment as the sea and wide asphalt roads received and stored more the solar radiation, shows steeper gradient then the vegetated environment. The plane area of transect-1 is thought to be influenced by fragmentation which also influences thermal diffusion and decreases the gradient of the edges that are surrounded by asphalt road.

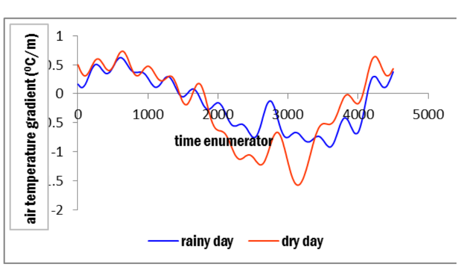
2. Grouping of transects based on plane area of air temperature vs air humidity gradients.





Figures 8 and 9 present groupings of transects in mangrove forests based on plane area of air temperature and air humidity gradient. Figures 8 and 9 show a grouping of transects with almost the same condition of environment and ecosystems. For example, transects 1, 2, 3, 5, and 9 are areas of Rizophora mangroves whose canopy density varies between 75% to 88% percent, and surrounded by the open sea. This transect group has a larger plane area of gradient dynamics than the group of transects 6, 7 and 8 transects which are overgrown by various type of mangroves, and canopy density between 64% to 70%. This group surrounded by bush forest. This grouping is consistent during the day and night.

3. Detect the influence of the weather



4. Detect the effect of gaps in the forest

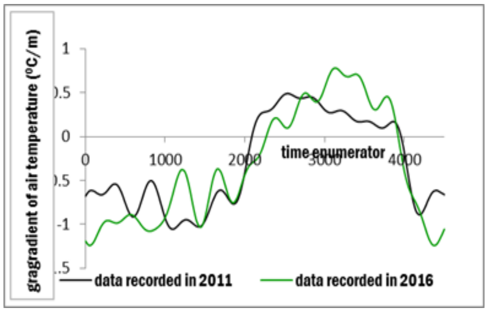


Figure 7 shows two graphs of the same transect, namely transect-1, located in Talengen Bay, which generated from the data, measured in different times. The black curve is a graph of the air temperature gradient dynamics in 2011 while the green graph is produced from the measurement in 2016. In that time period there was a change in the condition of the mangrove ecosystem. In 2011, inside the mangrove forest there was a gap of 30 m wide. The distance of the slit edge to the edge of the mangrove bordering the open sea is 68 m. In 2016 the gap was reduced to 18 m due to the natural growth of mangroves. The distance from the edge of the gap to the edge of the mangrove bordering the open sea increases to 76 m. The density of the mangrove canopy is relatively unchanged, which ranges from 72% -85%. Changes in the size of this gap are detected through changes in function and the plane area of air temperature gradient dynamics. The plane area of air temperature gradient derived from the first measurement data are 9.586^{0}C.hours/m at the day, and 3.034^{0}C.hours/m at night. In the second measurement, the plane area of air temperature gradient was 9.982^{0}C.hours/m at the day, 3.424^{0}C.hours/m at night.

Consistency with other micro-climate parameters

Stages of analysis and mathematical modeling for determining the function and plane area of daily dynamics of micro-climate gradient include parameters that have been used previously, namely: maximum magnitude of micro climate variables, maximum differences in forest edge and interior, edge effect depth, maximum edge gradient. Several results of study show the conformity between these parameters with the aplication of plane area of gradient dynamic parameter. The area of gradient dynamics is in line with the depth of the edge effect, for ecosystem conditions with a more dense canopy. These results are consistent with the research of edge effects carried out by Harper et al. (2005), Pohlman et al. (2007).Didham and Lawton (1999) and Pohlman et al. (2007), concluded that the temperature at the edge is higher if it is bordered by an open place. This is in line with the plane area of gradient dynamics which is large if the forest ecosystem borders open areas such as the sea.

The intensity of light intensity is influenced by cloud cover (Medellu, 2012), the orientation of the surface to the sun's trajectory (Renaud and Rebetez 2009) and slope and surface (Renaud et al, 2010). If these factors produce maximum intensity of illumination throughout the day, then the plane area of illumination gradient will be maximum. Forest canopies that are dense around the edges cause more steep irradiation gradients (Renaud et al., 2010, Dignan and Bren, 2003 in Schmidt et al, 2017), and produce the larger plae area of gradient dynamics.. Davies-Colley et al (2000) noted a steeper edge gradient for variable light intensity compared to air temperature and vapor pressure deficits (VPD). This corresponds to the larger plane area of daily dynamic of illumination gradient than the plane area of air temperature and humidity.

Conclution

Parameter the plane area of daily dynamics of microclimate gradients indicate the interaction of ecosystems with the environment as a result of the effects of sun radiation, absorption and thermal emissions by air, water, and soil surfaces. This parameter shows results that in line with other microclimate parameters in describing ecosystems and interactions with the environment. In the same weather conditions, for each transect, the plane area of daily dynamic of microclimate gradient value is relatively fixed compared to other parameters, so that it can be used to characterize ecosystems and environments based on thermal diffusion. These parameters can be used to distinguish ecosystem or environmental conditions, mapping or grouping ecosystem interactions with the environment, detect weather influences, detect the occurrence of gaps or changes in the interior of the forest.

Thank-you note

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References

Bellomo, N. E., De Angelis, and M. Delitala, 2007. Lecture Noteson Mathematical Modelling in Applied Sciences. http://staff.polito.it/marcello.delitala/dwd/mechanic_Simai.pdf

Davies-Colley R.J. , Payne G.W. and van Elswijk, M. 2000. Microclimate gradients across a forest edge. *New Zealand Journal of Ecology* 24(2): 111-121

De Lima B., Gilma N., Galvani E., 2013: Mangrove Microclimate: A Case Study from Southeastern Brazil. *Earth Interact.*, 17:1–16.

Didham R.K. and Lawton J.H. 1999. Edge structure determines the magnitude of changes in microclimate and vegetation structure in tropical forest fragments. *Biotropica*, 31(1): 17-30

Gehlhausen S.M., Schwartz M.W. and Augspurger C.K. 2000. *Vegetation and microclimatic edge effects in twomixedmesophytic forest fragments.* Plant Ecol. 147: 21 –35.

Harper K.A, Macdonald S.E.; Burton P.J., Chen J., Brosofske K.D., Sauders S.C, Euskirchen E.S., Roberts D., Jaiteh M.S., and Esseen P.A., 2005. Edge Influence on Forest Structure and Composition in Fragmented Landscapes, *Conservation Biology*, 19(3):768–782

Hennenberg K.J, Goetze D., Szarzynski J., Orthmann B., Reineking B., Steinke I., and Porembski S. 2008. Detection of seasonal variability in microclimatic borders and ecotones between forest and savanna. *Basic and Applied Ecology*. 9(3): 275 –285.

Ibanez T., Hely Ch., and Gaucherel C. 2012. *Sharp transitions in microclimatic conditions between savanna and forest in New Caledonia: Insights into the vulnerability of forest edges to fire.* Austral Ecology. doi:10.1111/aec.12015

Medellu Ch. S., Soemarno, Marsoedi, and S. Berhimpon. 2012. The Influence of Opening on the Gradient and Air Temperature Edge Effects in Mangrove Forests. *International Journal of Basic & Applied Sciences IJBAS-IJENS.* 12 (02): 53-57

Medellu Ch.S. 2012. Pemodelan Matematik Dinamika Harian Gradien Iklim di Hutan Mangrove. *Disertasi*-Universitas Brawijaya, Malang.

Medellu Ch. S. 2013. The area and index of diurnal dynamic of microclimate gradient as a mangrove – environment interaction parameter. *Journal of Natural Sciences Research.*, 3(14), 2013. ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)

Medellu Ch.S. and Tulandi D. 2018. Parameter: the area of microclimate gradient diurnal dynamic for characterization and monitoring of forest ecosystem and environment. *International Journal of Environment, Agriculture and Biotechnology (IJEAB)*, 3(3): 2168-2175

Medellu Ch.S. and Tulandi D. 2018. Parameter: the area of microclimate gradient diurnal dynamic for characterization and monitoring of forest ecosystem and environment. *International Journal of Environment, Agriculture and Biotechnology (IJEAB)*, 3(3): 934-943.

Newmark W.D. 2001. Tanzanian forest edge microclimatic gradients: dynamic patterns. *Biotropica* 33: 2 –11

Pohlman C.L., Turton S.M., and Goosem M., 2007. Edge effects of linear canopy openings on tropical rain forest understory microclimate. *Biotropica*, 39: 62-71.

Renaud, V., Rebetez, M., 2009. Comparison between open-site and below-canopy climatic conditions in Switzerland during the exceptionally hot summer of 2003. Agric. For. Meteorol. 149, 873–880, http://dx.doi.org/10.1016/j.agrformet.2008.11.006.

Renaud V., Innes J.L., Dobbertin M, and Rebetez M. 2010. Comparison between open-site and below-canopy climatic conditions in Switzerland for different types of forests over 10 years (1998−2007). *Theor Appl Climatol* DOI 10.1007/s00704-010-0361-0. Springer-Verlag 2010

Schmidt M, Jochheim H, Kersebaum K, Lischeid G. Nendel, C.2017. Gradients of microclimate, carbon and nitrogen in transition zones of fragmented landscapes – a review.*Agricultural and Forest Meteorology*, 232 (15): 659–671

Stewart K.J. and Mallik A.U. 2006. *Bryophyte responses to microclimatic edge effects across riparian buffers*. Ecol Appl. 16(4):1474-1486