Foraged biomass of the Leaf-Cutter Ants *Atta Cephalotes* and *Acromyrmex coronatus*: findings from research undertaken at the field station of Rancho Grande in Henri Pittier National Park, Venezuela

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Abstract

The aim of the study was to estimate the biomass that leaf cutting ants foraged to their nests as food for their fungal gardens. Two nests were observed: one belonging to *Atta cephalotes* and the other one to *Acromyrmex*; both had nocturnal activity. Material gathered from ants was taken to the laboratory and provided data for further analysis. The results obtained showed that the *Atta cephalotes* colony was able to forage about 150 kg wet biomass per year, while the *Acromyrmex* colony would forage nearly 31 kg wet biomass per year. Rainfall intensity may have important impact for colony activity of *Atta cephalotes*.

KEY WORDS: Leaf cutting ants, foraged biomass, fungal gardens.

Introduction

Leaf cutting ants have been the subject of many studies made by researchers, notably E. O. Wilson and B. Hőlldobler. "Leaf cutting ants" is a non-generic name. These species of tropical ants belong to the two genera *Atta* and *Acromyrmex*, and are endemic to South and Central America and southern parts of North America. These ants are especially famous for their fungal gardens. In each nest can be find only one species of fungus which requires the leaves of specific plant species. The foragers cut mainly green leaves and transport them into the nest. Later, leaves are cut into small pieces and chewed by the cast of the smallest ants which take care of the fungus. The main food consumed by ants is not leaves, but special parts of the fungus *gongylidia*, which are rich in carbohydrates and proteins. Mature colonies in the genus *Atta* may consist of several million workers (E. O. Wilson & B. Hőlldobler 1990). Leaf cutting ant species of the genus *Atta*, with a total of 15 species, have the largest herbivory impact in most habitats of the New World tropics (Wilson 1980). They may account for the destruction of up to 17% of the total leaf production in tropical rainforests (Begon 1996). Leaf cutting ants cause deforestation and may have an important effect on forest succession on abandoned land (Moutinho et al., 2003). The main aim of our study was to estimate the biomass of leaves transported into the nest by ants and compare this value between colonies of *Atta cephalothes* and *Acromyrmex coronatus*.

Material and methods

The project was set in the Venezuelan field station “Rancho Grande” of the Faculty of Agronomy, Central University of Venezuela, Maracay in Henri Pittier National Park in July 2010, during the wet season. The station is located in mountain cloud forest at an elevation of 1157 meters (10°20'57.3" N and 67°41'03.8" W). The average annual temperature at the station is 20°C with precipitation of 1523 mm. The dry season is not strongly marked and there do not occur great daily or seasonal extremes. For our research we found one nest of *Atta cephalotes* and one nest of *Acromyrmex coronatus*. The *Atta cephalotes* nest, called A1, was located in the forest below the road connecting Ocumare with Maracay (10°20'54.9" N and 67°41'09.7" W). The *Acromyrmex coronatus* nest, called A2, was located next to the Rancho Grande field station building (10°20'56.7" N and 67°41'04.6"W). The A1 and A2 colonies differ in the environment that they occupy and the diet.

The project was planned for 7 nights between 10.07.2010 to 17.07.2010. In the beginning we marked all active entrances to both nests. For A1 we found two active entrances (SC1 and SC2) and for A2 we found one active entrance. We did our observations during each evening from 06.30p.m to 10.30p.m and each morning from 04.00a.m to 06.00a.m. Due to logistic limitations and safety precautions observations could not be continued all night, so we had to interpolate the values of late evening and early morning.

Every night we noted the hour when ants started and finished their activity. Each evening, one hour after the start of activity, we were collecting 50 pieces of leaves on each path and each nest. Just after collecting leaves we were estimating the activity of ants by counting the number of leaves transported into the nest during the period of 10 minutes. We were taking the activity measurements two times in the evening and once in the morning for each nest. The activity was expressed as the number of ants per one minute. Later we approximated all night activity using mathematical equations, on an optimal basis for each night. To estimate the foraged biomass we were counting an integral from each graph for every night. The laboratory part was to estimate the average weight of one particular piece and to find some differences between the weight of pieces carried from different places. We weighed all wet leaves together on the electronic portable balance. Moreover we estimated the average surface of transported leaves.

For statistical analysis we used Microsoft Excel and Statistica 9.0 software.

Results

During our observations we noticed that both nests had nocturnal activity. At the *Atta cephalothes* nest we found the biggest cast of soldiers and young queens ready for their mating flight, which allowed us to presume that this nest was about 10 years old. We discovered that the main source of material for the *Acromyrmex coronatus* colony was fruits (Fig. 1), while the *Atta cephalothes* colony depended 100% on leaf material. We identified two species of plant from which the *Atta cephalothes* colony was gathering material: *Heliconia sp* and *Asplundias sp*, while the *Acromyrmex coronatus* colony was gathering mainly pieces of banana. We estimated the weight of an average piece of carried leaf, which was 16.32mg of wet biomass (7.1 mg dry mass) with average surface of 128mm^2. The weight of an average piece of fruit was 10.16 mg. We did not find significant differences in length of activity (9.30 h), also the hour of commencement of activity did not differ between both species but the finish time differed, being 5.45a.m. for *Atta cephalothes* and 5.15a.m. for *Acromyrmex coronatus* ($p=0.0004$). We noticed that the occurrence of rain up to 6 hours before the start of the activity caused a decrease in foraging biomass (Fig. 2, Fig. 3), but the influence of rain was statistically significant only for the *Atta cephalothes* nest ($p=0.0025$). We also found a statistically significant difference between average biomass input in the *Atta cephalothes* nest (415g wet biomass per night) and the *Acromyrmex coronatus* nest (97g wet biomass per night) with $p=0.006$. Comparing the weight of material transported into the nests (Fig. 4), we can say that the *Atta cephalothes* colony is bigger than *Acromyrmex coronatus*. Moreover we can predict that the *Atta cephalothes* colony forages nearly 150 kg wet biomass per year (65.26 kg dry mass), while *Acromyrmex coronatus* forages only 31 kg wet biomass per year. On the base of average trail length we estimated the average area controlled by *Atta cephalothes* nest as a circle with 323m^2. Dividing foraged biomass by controlled area we can say that *Atta cephalothes* forage about 0.202 kg m^{-2} year^{-1}. On the base of previous research (Chave et al. 2009), we assume that net primary production in this area can be about 2.56 kg

m^{-2} $year^{-1}$. We estimated that *Atta cephlothes* colony can consume about 7.89% of total net primary production in the area around the nest.

Discussion

In this research we tried to estimate the impact of leaf cutting ants on vegetation, thinking mainly about direct effects caused by defoliation. If we assume that one third of NPP is leaf production (Clark D.A et al. 2001), then *Atta cephalothes* may be responsible for 23.7% of defoliation in the controlled area, which is even more than the 17% claimed by Bergon (1996). Removal of large amount of leaves may affect plant biomass production and occasionally lead to tree mortality in the vicinity of the colony (Rockwood 1975). Unfortunately such impact on vegetation indicates that *Atta cephalothes* can be a major economic pest in tropical forest plantations. In this study area *Atta cephalothes* had a much bigger impact on vegetation than *Acromyrmex coronatus* but we should remember that the *Acromyrmex* colony was probably younger and smaller than *Atta*. Influence on vegetation by leaf cutting ants may be also indirect. Injuries caused to leaves open the possibility of infection by fungi, bacteria and viruses. Indirect effects include soil nutrient enrichment from nest refuse dumps and transferring nutrient to upper soil layers (Weber 1972). We also proved that for *Atta cephalothes,* the occurrence of rain up to 6 hours before the start of the activity caused a decrease in foraged biomass.

Acknowledgments

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Tables and figures

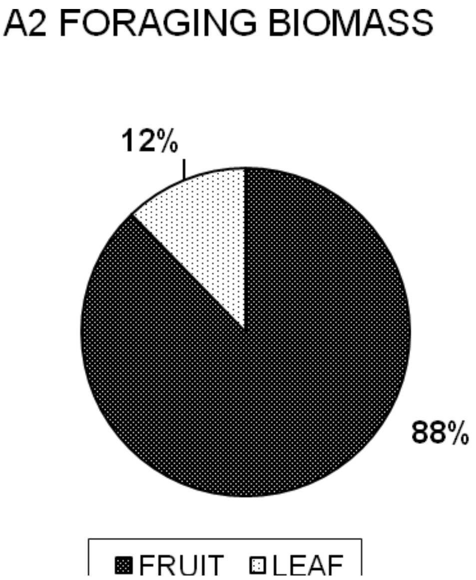

Figure 1. Percentage of foraging biomass in *Acromyrmex coronatus* A2 colony.

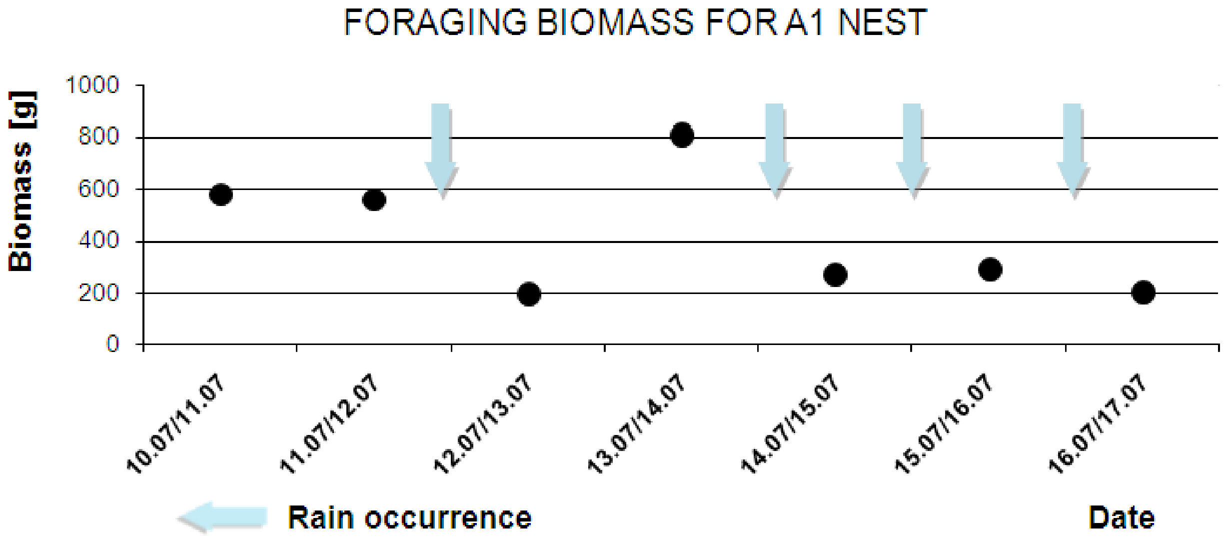

Figure 2. Relation between rain occurrence and foraging biomass for *Atta cephalothes* (A1) nest.

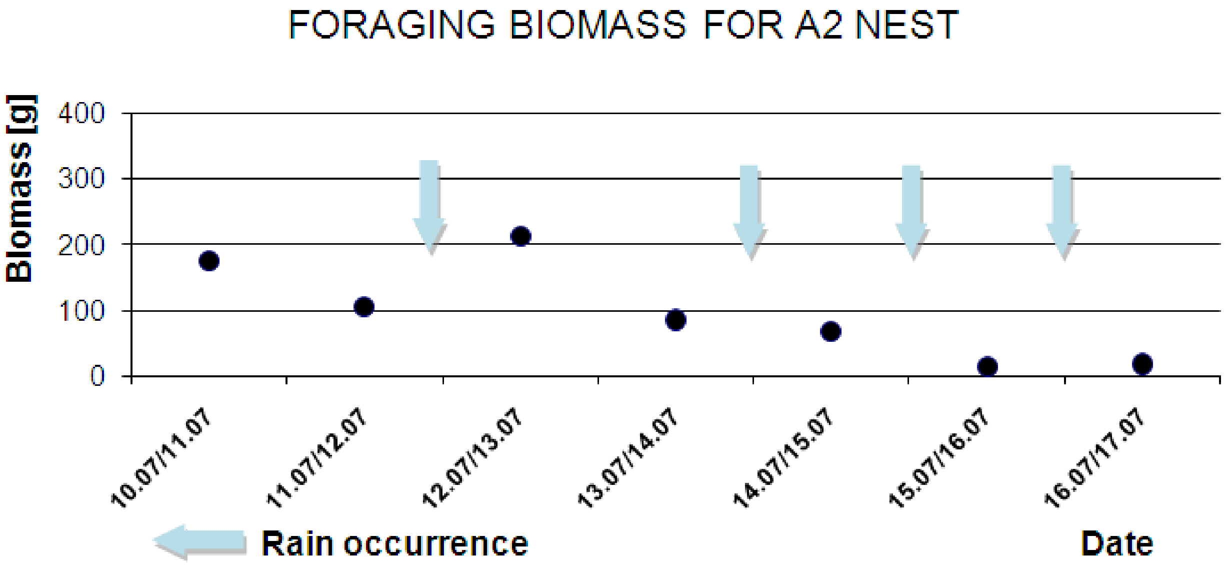

Figure 3. Relation between rain occurrence and foraging biomass for *Acromyrmex coronatus* (A2) nest.

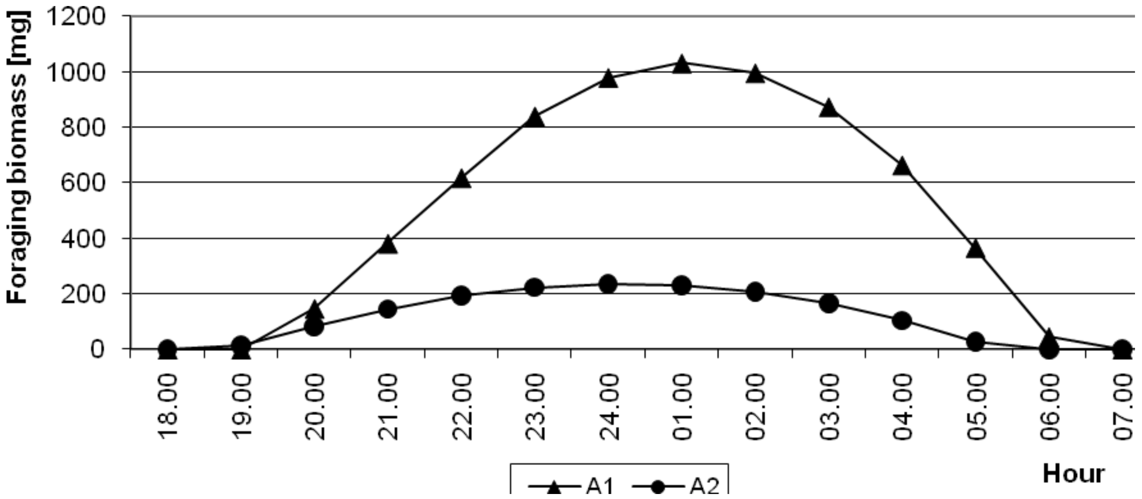

Figure 4. The average foraging biomass for *Atta cephalothes* (A1) and *Acromyrmex coronatus* (A2) nest, during night hours for one week of observations.

Migration of Lepidoptera through the Portachuelo Pass in the Coastal Cordillera of Venezuela. A study of the effect of wind velocity and direction on Lepidoptera numbers

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Abstract

The southwards migration of Lepidoptera was observed in the Portachuelo Pass from 10 to 17 July 2010 during the rainy season with a view to examining the influence of wind direction and wind velocity on Lepidoptera numbers. This study clearly reveals the strong association between numbers of migrant Lepidoptera and wind direction: the highest intensity of the migration was observed when the wind blew from south to north in the opposite direction to the migration. However, statistical analysis shows no significant differences in intensity of Lepidoptera migration in relation to wind velocity.

Key words: butterfly, Lepidoptera, migration, Portachuelo Pass, wind velocity, wind direction

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1. **Introduction**

The Portachuelo Pass is the lowest pass in the Coastal Cordillera of the Andes. Because of this the Portachuelo Pass is a natural migration route for insects flying from distant places. Such a migration was confirmed for many species of butterflies and moths of different families [1-5].

The migration of butterflies has been observed in many other places all over the world and the distance in some cases can be long. The most spectacular example is that of the Monarch butterfly, *Danaus plexippus* (L.), famous for its southward migration to Mexico and its northward return the next season to North America which spans the life of three to four generations of the butterfly. Butterflies exhibit not only long-distant migrations but also short-distant migrations which are strongly affected by the weather conditions. There are some papers showing the significant influence of climatic factors like the amount of sun radiation, the temperature, wind direction and wind velocity on butterfly flight [6] and migration [7-10].

This research concentrated on the effect of wind, an important atmospheric factor, on the migration of butterflies over the Portachuelo Pass in North Venezuela..

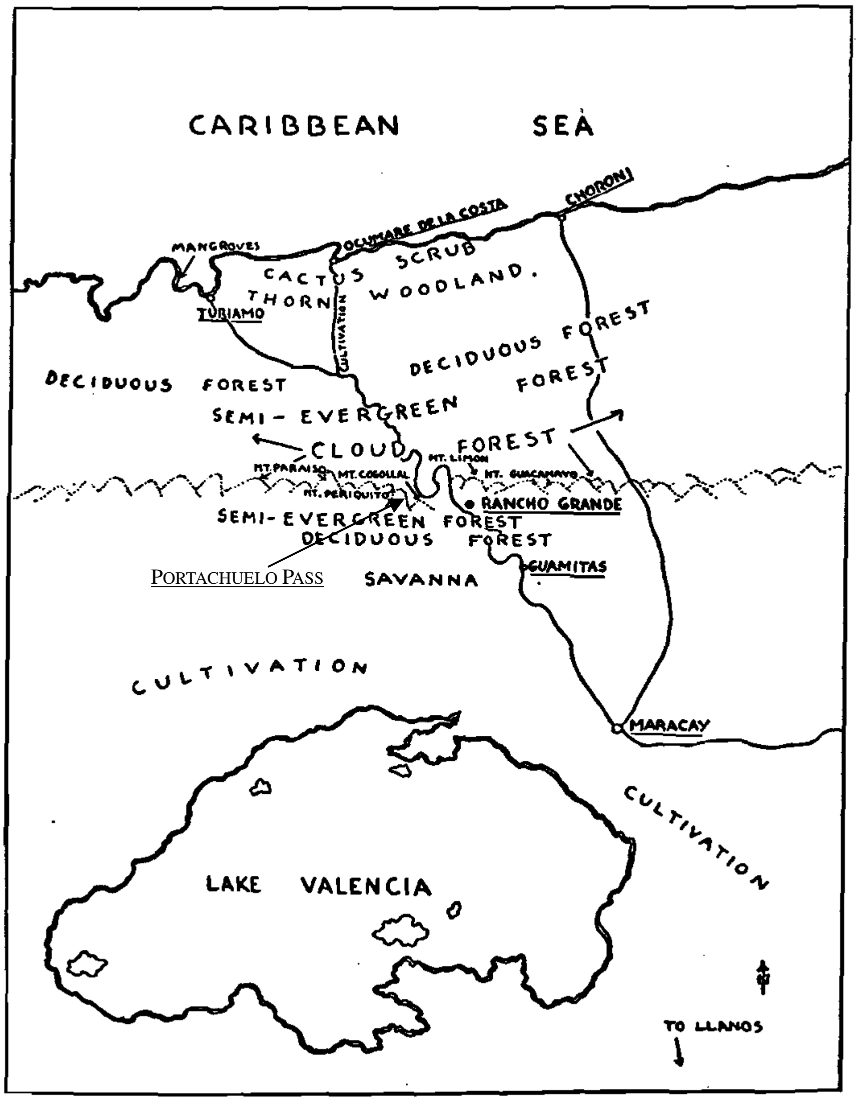

Fig.1. Location of the migration observation site on the Portachuelo Pass, in Coastal Cordillera of the Venezuelan Andes and general location map of the principal ecological zones. Scale: 1cm = 4.7km [1]

2. Material and Methods

Our study was conducted on the Portachuelo Pass, which is the lowest pass (1128m) in the Coastal Cordillera of the Venezuelan Andes. The Portachuelo Pass is located in north-central Venezuela (10°20'N ; 67°41W), about 200m from Rancho Grande Biological Station of the Central University in Maracai (Fig. 1).

Our research took place from 10 July to 17 July 2010. The observations were made three times per day, one hour in the morning from 7am to 8am, two hours from 10am to 12pm and one hour in the afternoon from 2.30pm to 3.30pm.

During each observation period we were counting the number of butterflies flying over the pass and identified them by family. In come cases where immediate identification was not possible, flying individuals were caught by means of a butterfly net and then photographed for later identification.

To measure wind direction and velocity we used simple equipment. We put a 146cm long stick into the ground and attached a 65cm long ribbon on its top. The angle at which the ribbon drew aside from a vertically fixed stick was assumed as an indication of a wind velocity (Tab.1); the wider the angle, the stronger the wind.

The number of migrants in each Lepidoptera family was correlated with wind direction and wind velocity.

ANOVA statistical analysis was used to show significant differences between groups.

Tab.1. Wind velocity scale.

Number of wind velocity on a scale	The angle between the ribbon and the stick
0	0°
1	18°
2	36°
3	54°
4	72°
5	90°

3. **Results**

During our observation we identified 7 families of butterflies: Nymphalidae, Ithomidae, Danaidae, Hesperidae, Lycaenidae, Pieridae, Papilionidae. On each day the number of individuals belonging to those families differed (Tab.2).

Tab.2. Quantity of butterflies on each day of observation.

Name of Lepidoptera family	1st day observation (10.07.2010)	2nd day observation (11.07.2010)	3rd day observation (13.07.2010)	4th day observation (14.07.2010)	5th day observation (16.07.2010)	6th day observation (17.07.2010)
Nymphalidae	5	56	25	56	288	16
Ithomidae	9	39	13	30	78	15
Danaidae	27	22	1	3	14	1
Hesperidae	991	7	3	1	1	0
Lycaenidae	3	136	4	8	176	354
Pieridae	8	60	20	51	124	1
Papilionidae	2	3	0	1	0	0

During each day, three observations were planned. However, because of unpredictable weather conditions, not all observations could be completed as planned. The activity of migrating butterflies was generally low. However, it increased significantly during the second observation period in each day. During the first and third observation period its level was low, or there was no migration at all.

To examine the influence of wind direction on the intensity of Lepidoptera migration we divided migrating butterflies into four groups: 1) butterflies flying from sea to land against the wind, 2) butterflies flying from sea to land with the wind, 3) butterflies flying from land to sea against the wind, 4) butterflies flying from land to sea with the wind (Fig. 2). The influence of wind direction was revealed in the numbers of observed migrants classed to each group. In all observed Lepidoptera families significant correlations was found between wind direction and migration direction (p=0.02).

It was observed that numbers of migrating butterflies varied with the variation of the wind velocity (Fig. 3). However, results of statistical analysis indicated that those differences were not statistically significant and probably a very high variance was responsible for such a result (p=0,20).

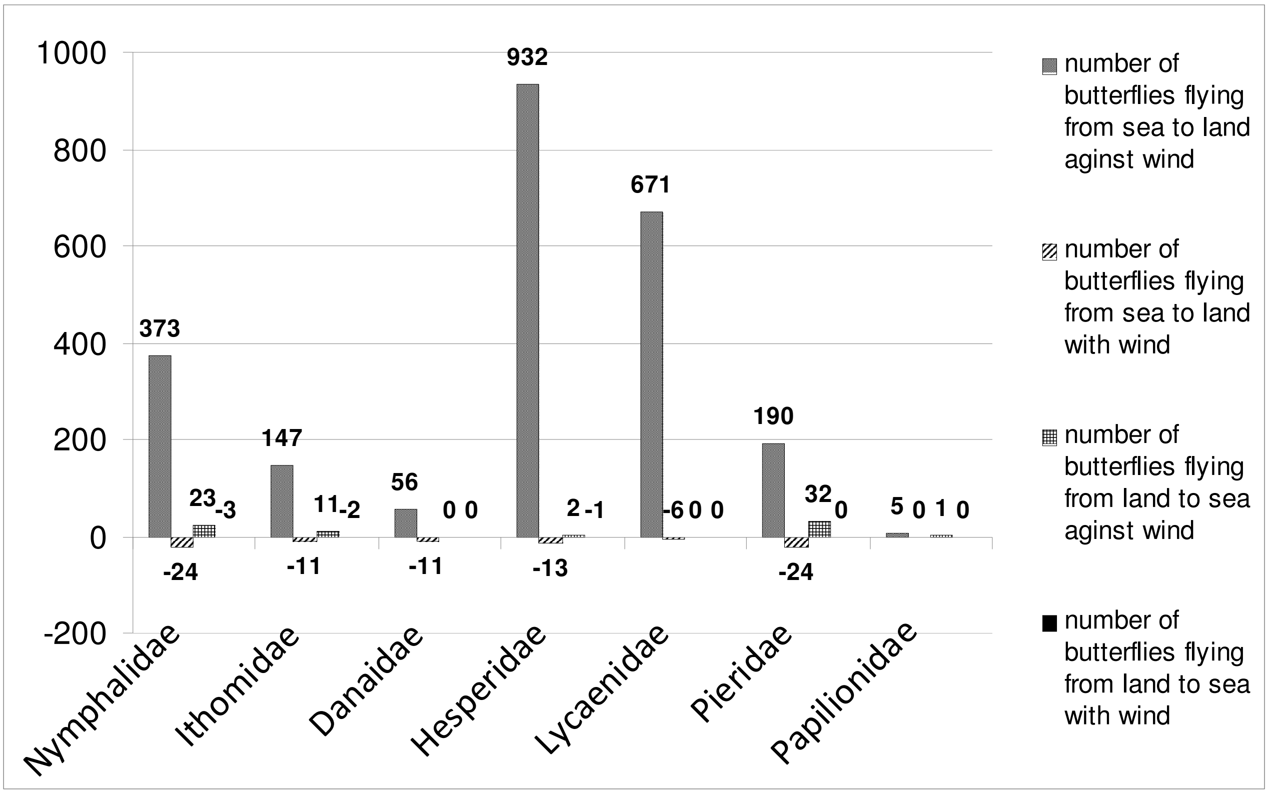

Fig.2. Correlation between wind direction and migration direction.

4. Discussion

When analyzing the results of our observations we have to point out that the migration we were able to observe at this time of the season was in fact the end of the phenomenon of seasonal migration in Coastal Cordillera area. This is why the intensity of migration observed by us was so low, much lower than that reported by other authors [10]. During each day migration started at about 8am, or later. On the third day of observation at 2:30 pm almost no butterflies were observed. The exception to this was a day in which rain started early in the morning causing the beginning of migration to shift towards midday.

Our data shows that wind direction influences Lepidoptera migration and negatively correlates with the direction of migration (Fig. 2.). Such a negative correlation was a surprising finding for us. We were expecting the butterflies to migrate down wind to accelerate their flight speed [11]. The possible explanation of this negative correlation could be that the wind is distributing sex pheromones downwind so that their source can be detected easier when flight is oriented upwind. Another possible explanation is that insects having poor vision [12] may rely mostly on smell to detect the correct migration direction.

Statistical analysis revealed that differences in intensity of migration in relation to wind velocity are not significant. However, results obtained by other authors suggest that wind velocity affects the Lepidoptera migration [6]. During our observations we found that wind velocity of the value 2 and 3 was the most favourable for the migration (Fig.3). We suppose that such a wind velocity is not disrupting butterflies' pheromone communication, so they are still able to fly against the wind. There is also a paper [8] suggesting that the wind must reach a certain velocity to blow away fog, or clouds and open the view to the sky. To see the sky is a very important condition for butterflies which use the sun, or landmark orientation, when navigating during migration [6,8].

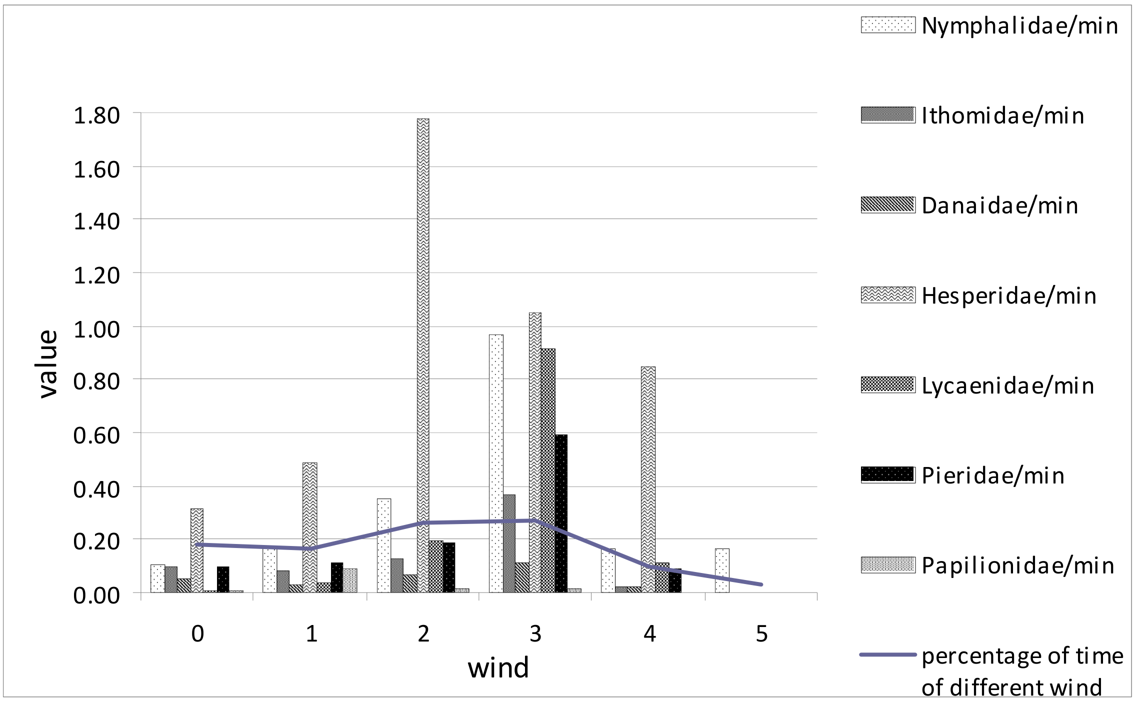

Fig.3. Correlation between migration intensity and wind velocity

We suppose that the lack of statistical significance in the analysis of our data results perhaps from: 1) too small a number of completed observations, which resulted in a very high value of variation 2) lack of more precise wind measuring equipment what could be used in the field and enable us to capture some important data.

5. **Acknowledgements**

We thank Dr John Lattke (Central University, Venezuela) for allowing us to access Portachuelo Pass and work in Rancho Grande research station. We also thank Professor Janusz Wojtusiak (Jagiellonian University, Poland) for his support and his help in the identification of migrating Lepidoptera specimens.

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The Diversity of Moths in Rancho Grande Field Station in Tropical Cloud Forest, Northern Venezuela.

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Abstract

The purpose of the study was to investigate the flight activity of moths of the most numerous families and subfamilies of Lepidoptera being attracted to light at the Rancho Grande Field Station in the Henri Pittier National Park. During seven consecutive nights of observations from 10-17 June 2010 the air temperature and relative humidity were measured and correlated with data on numbers of moths attracted to the artificial light. The most numerous appeared to be the species of the family Pyralidae and Noctuidae, especially the subfamily Ophiderinae.

The study revealed a significant positive correlation between the number of moths and the air temperature and humidity conditions.

Introduction

The tropical cloud forest of the Cordillera de la Costa in Venezuela is characterized by high humidity and precipitation. Within the cloud forest, much of the precipitation occurs thanks to condensation where droplets of water condense on tree leaves and then fall down to the ground. Patches of mountain cloud forest often isolated from each other by deep valleys, tend to have many endemic species. Besides South and Central America, cloud forest ecosystems are to be found in other parts of the world including East- and Central Africa, Indonesia, Malaysia, the Philippines, Papua-New Guinea and in the Caribbean [1].

For this project, the mountains of the Cordillera de la Costa in the northernmost part of Venezuela were chosen. This is one of the most interesting ecosystems in South America, known for its high species diversity. Its specific geological structure and climatic conditions, as well as the isolation from the other parts of the Andes, have had a significant impact on the distinctiveness of its fauna and its high level of endemism. The biodiversity heritage of cloud forests is obviously of great global importance. [2,3].

The main aim of this research was to identify families and subfamilies of moths that were attracted to light during the night in Rancho Grande Biological Station situated in the

Henry Pittier National Park, and to correlate the changes in numbers of moths arriving to light in relation to changes in temperature, humidity and time.

It is well known that moths keep the direction of their flight in the reference to the position of Moon and bright stars visible on a night's sky, the orientation phenomenon known as menotaxis. Since the artificial light is much closer than are the sources of natural light, moths instead of keeping straight path of their flight are turning toward the source of artificial light [4,5].

Materials and Methods

Observations were carried in Rancho Grande Biological Station in the northern part of Venezuela in the Cordilliera de la Costa in Parque Nacional Henri Pittier, the oldest national park of Venezuela, established in 1937 (Fig. 1). It covers an area of 1078 sq. kilometers. The research site was at an elevation of 1100 meters above sea level. [2].

To observe moths arriving to the light, a white sheet was placed vertically on a wall of the verandah of the Rancho Grande station; the sheet was divided by a marker into six squares, each with a dimension of 70x52cm. (Fig.2). A wide spectrum of light was achieved by the use of two kinds of bulb: the UV bulb and the fluorescent tube (both 100W). Air temperature and humidity were measured by thermometer and hygrometer. Moths arriving to light and resting on the white sheet were photographed by means of a high resolution, 12 megapixel digital camera.

Observation was carried out from 10th to 17th of June 2010. The light was turned on at 6:00pm and kept on until 9:30pm. Every half an hour, one picture was taken of the surface of each square of the white sheet with the moths resting on them. Each evening 42 photographs were taken and then analyzed to identify the family and subfamily to which the moths photographed belonged to. All obtained data were put into tables for comparison (Tab. 1). Temperature and humidity was measured every half an hour every evening to get the average value.

Results

After seven days of observations all the data were analyzed and summarized (Tab. 2) . It can be seen that the largest number of species were those from the family Pyralidae with more than 2600 specimens, and Noctuidae of the subfamily Ophiderinae with more than 2000 specimens (Fig.3). The less numerous were species of Noctuidae of the subfamily Catocalinae and Amphypyrinae. Measurements of air temperature and humidity varied on different days (average values are contained in Tab. 3).

To perform a statistical analysis we took a number of specimens representing the three the most numerous groups of moths: Ennominae (Geometridae), Ophiderinae (Noctuidae) and Pyralidae. The linear regression that was calculated revealed a statistically significant correlation where the rise of the temperature and humidity was reflected in increasing number of moths representing the above groups (Fig. 4 and 5)

Another aim of this paper was to record the time at which representatives of different families of moths were arriving to light and the time when their abundance was the highest. Our analysis revealed that representatives of almost all groups of moths appeared after 7.00pm. After that time the number of species of each family was still increasing, except for the species belonging to the subfamily Hypeninae (Noctuidae) and the family Drepanidae where there was a decrease after 9:00 PM (Fig. 6 and 7).

Discussion

There are some other, very important factors that influence moth reaction to light. These are Moon phases, level of air ionization and some weather conditions like rain, fog, or wind. To lessen the influence of the Moon the seven nights of observation were selected around the New moon phase.

Of the seven nights, two appeared to be especially interesting and in both the air was warm and humid. Both were characterized by a very large number of moths attracted to light. But the species dominating in each of the two nights belonged to different families. The differences might be caused by different intensity of rainfall that started at different times of the night and the presence or absence of fog.

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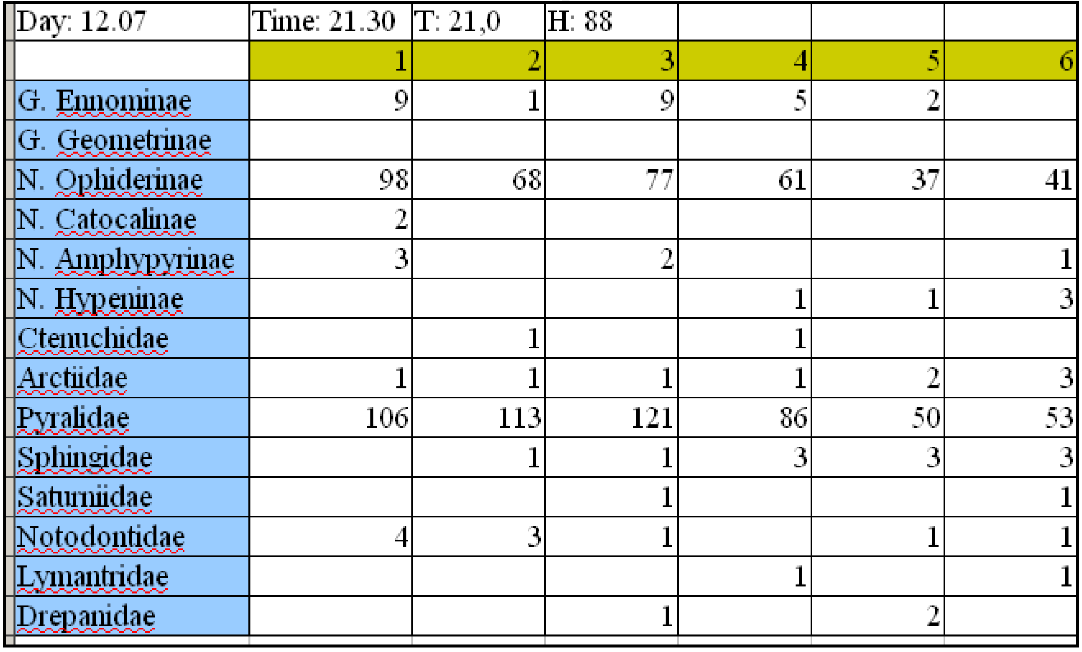
Tables and figures

Table 1. Example of table with data.



Day: 12.07	Time: 21.30	T: 21,0	H: 88			
	1	2	3	4	5	6
G. Ennominae	9	1	9	5	2	
G. Geometrinae						
N. Ophiderinae	98	68	77	61	37	41
N. Catocalinae	2					
N. Amphypyrinae	3		2			1
N. Hypeninae				1	1	3
Ctenuchidae		1		1		
Arctiidae	1	1	1	1	2	3
Pyralidae	106	113	121	86	50	53
Sphingidae		1	1	3	3	3
Saturniidae			1			1
Notodontidae	4	3	1		1	1
Lymantridae				1		1
Drepanidae			1		2	

Table 2. Number of moths' representatives in all seven days of observations.

	10.07	11.07	12.07	13.07	14.07	15.07	16.07	Total
Geom. Ennominae	181	69	84	70	107	41	42	594
Geom. Geometrinae	11	2	1	19	11	3	2	49
Noct. Ophiderinae	451	168	971	222	178	40	30	2060
Noct. Catocalinae	5	0	2	8	1	2	1	19
Noct. Amphypyrinae	12	1	9	2	2	0	0	26
Noct. Hypeninae	22	29	27	35	39	27	23	202
Ctenuchidae	8	1	13	2	4	10	10	48
Arctiidae	47	9	42	10	28	4	3	143
Pyralidae	415	168	1328	378	239	71	54	2653
Sphingidae	28	0	27	13	18	4	3	93
Saturniidae	5	3	4	15	9	5	5	46
Notodontidae	29	9	26	4	2	0	0	70
Lymantridae	37	23	11	10	61	5	4	151
Drepanidae	3	17	13	5	6	3	2	49

Table 3. Number of moths of the three most numerous families appearing in different values of humidity (H).

H (% r.h.)	total amount	log total amount
83.71	215	2.33
84.00	179	2.25
84.57	793	2.90
85.43	499	2.70
87.29	705	2.85
87.57	1254	3.10
88.00	2558	3.41

Table 5. Amount of moths representing three most numerous families appearing in different values of temperature (T).

T (°C)	Total amount	Log Total amount
19.76	126	2.100371
19.81	152	2.181844
20.19	670	2.826075
20.40	524	2.719331
20.54	405	2.607455
20.84	2383	3.377124
20.93	1047	3.019947

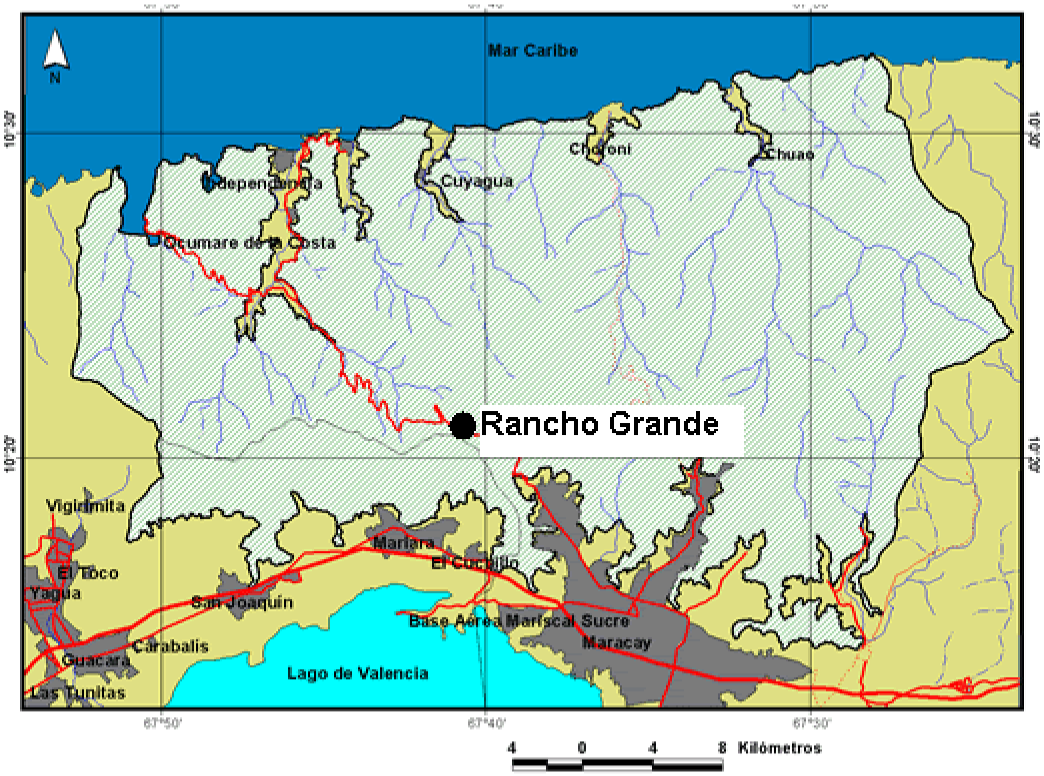


Figure 1. Map of Henri Pittier National Park.

Figure 2. Observation site on the Rancho Grande Station terrace.

Table Average va es of temperature d humidity n 7 d s of observation

Date	10.07	11.07	12.07	13.07	14.07	15.07	16.07
Temperature	20,93	20,54	20,84	20,19	20,40	19,81	19,76
Humidity	87,57	85,43	88,00	84,[illegible]	87,29	83,71	84,00

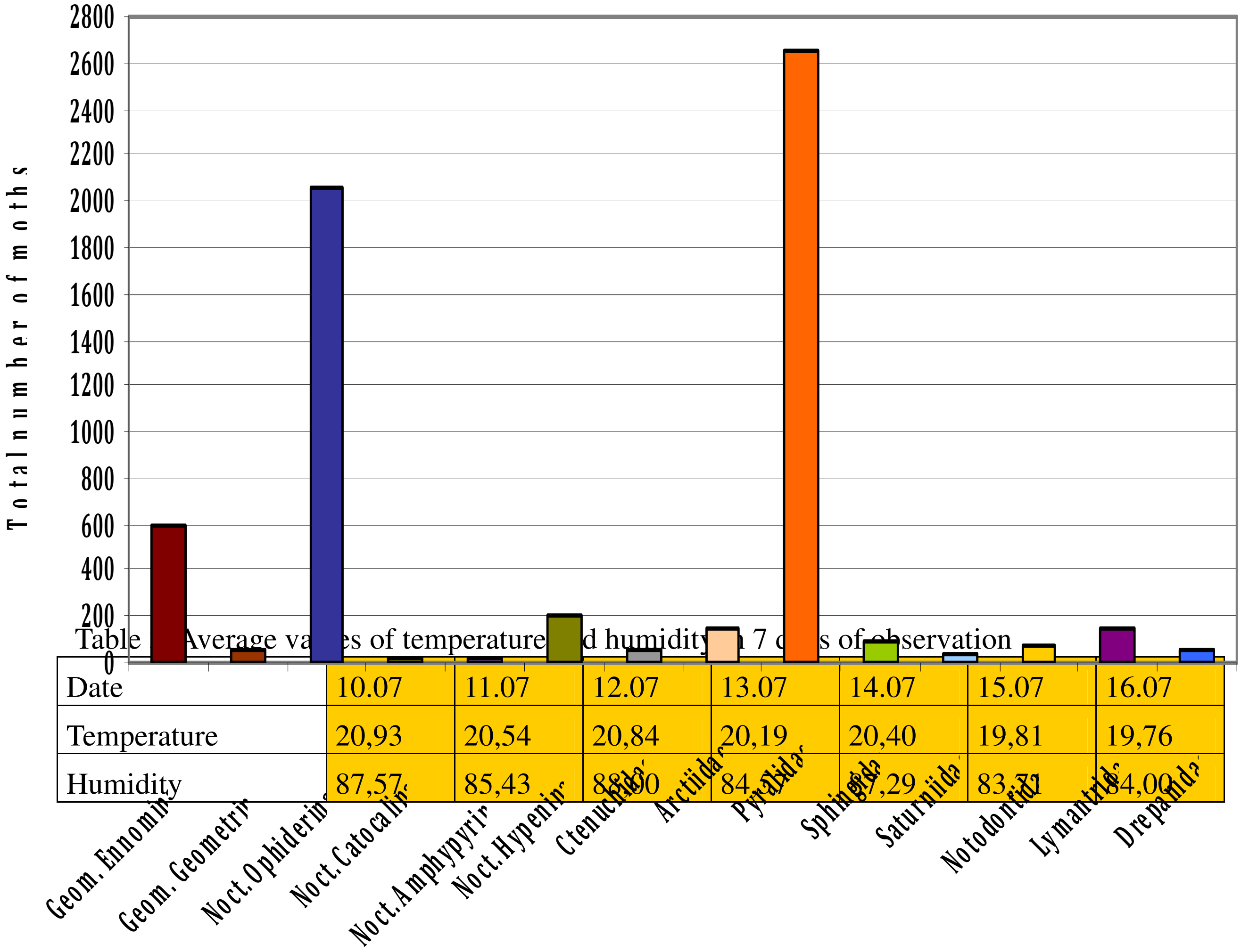


Figure 3. Total number of moths in 7 nights of observation

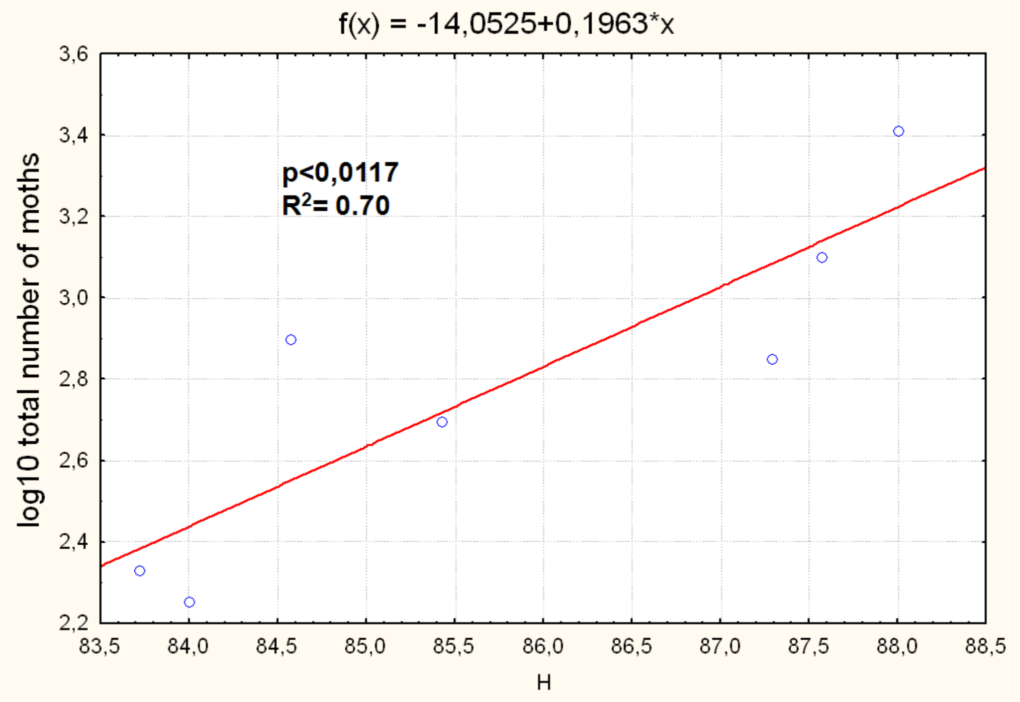


Figure 4. Multiple Regression Analysis of total number of moths and humidity

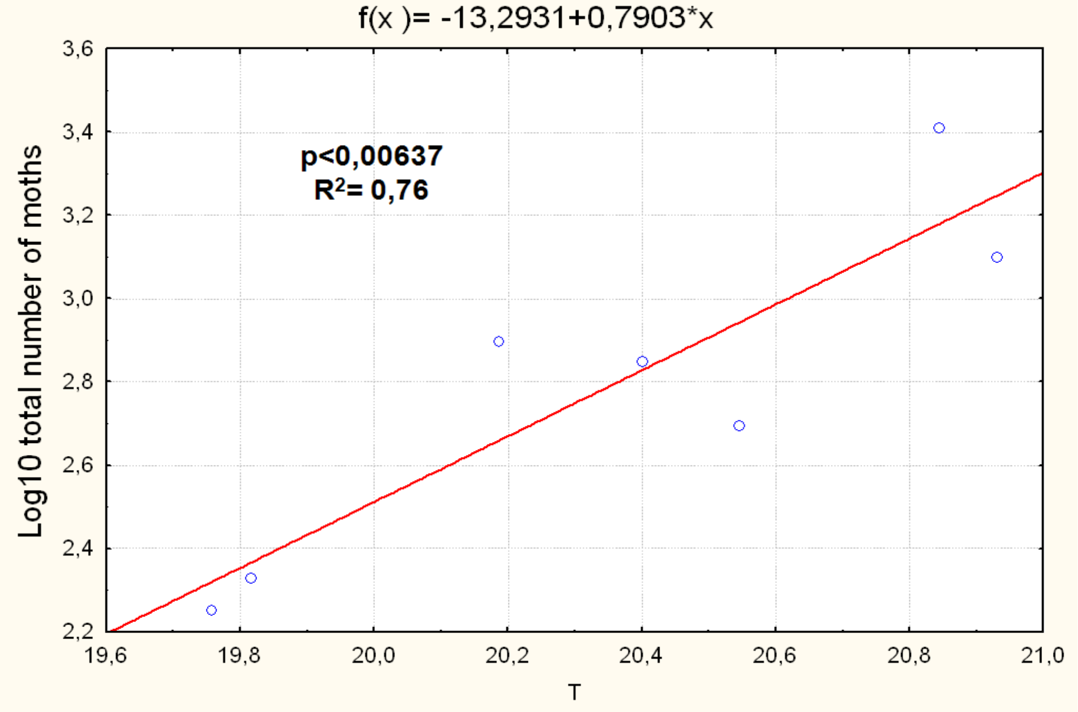


Figure 5. Multiple Regression Analysis of total number of moths and temperature

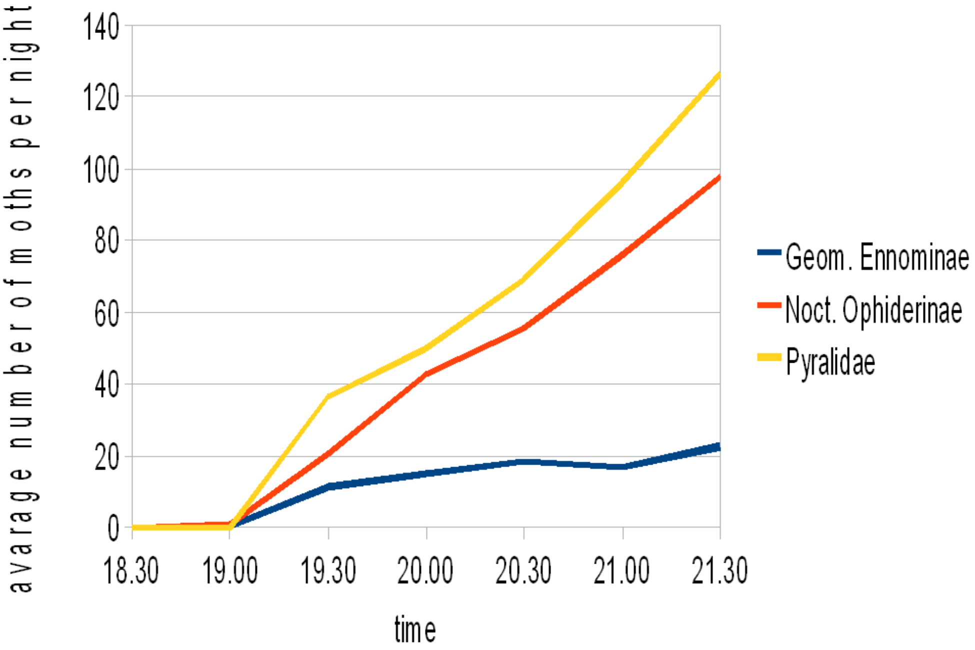


Figure 6. Change in frequency of the most popular families in time

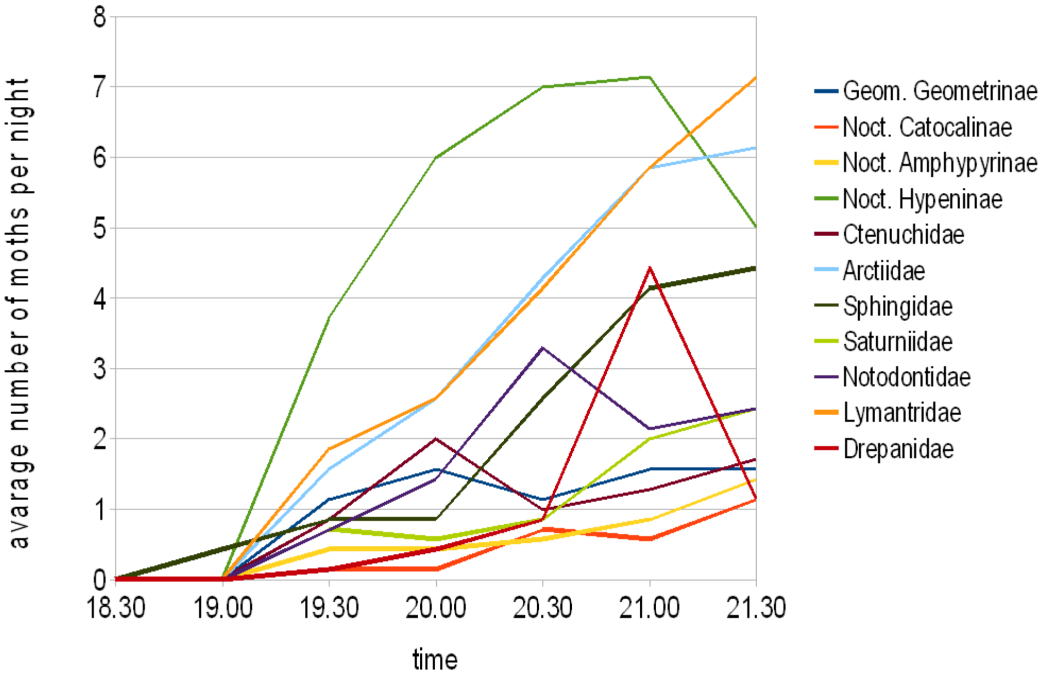


Figure 7. Change in frequency of other families in time

Soil respiration in mountain cloud forest, Henri Pittier National Park, Venezuela

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Abstract

Soil respiration is a process of fundamental importance in the forest ecosystem. On different latitudes there are different climatic conditions, and because of that there are differences in the biomes. The main goal of this study was to measure the rate of respiration in one of the most diversified ecosystems on earth: the mountain cloud forest of the coastal cordillera of Venezuela. The study was conducted as part of a tropical ecology field course at Rancho Grande in the Henri Pittier National Park. Investigations were carried out in the mountain cloud forest in the altitude gradient 1100-1400 m a.s.l. during one week, 14-21 July 2010. Samples were taken also from the *Atta* sp. nest and from the soil surface after litter had been removed, and from places located outside the forest: a cocoa plantation and a tract of forest along the side of the road from Maracay to Occumare de la Costa. There was no statistically significant relationship between respiration rate and altitude, whereas there were statistically significant differences between the forest and the plantation. The respiration rate of the *Atta* nest sampling was twice as high as the respiration rate of the forest sampling, which points on yet another role of ants in the biomass cycle. This study attempted to identify factors which influence the rate of soil respiration in this tropical part of the world. An understanding of this process is fundamental to the conservation and management of forests.

Keywords

Soil respiration, biomass, tropical cloud forest, decomposition, Venezuela, Henri Pittier National Park, soil ecology, tropics.

Introduction

Soil respiration, depending on microbiological activity, is a fundamental ecosystem process. It can be described as the biological method of oxidizing carbon compounds to carbon dioxide, which is conducted mainly by bacteria and fungi. Thus, the respiration rate corresponds to decomposition of the organic matter and, as well, to the carbon cycle in the soil system. The knowledge of soil parameters enables the prediction of other measures like decomposition rate, nutrient richness and productivity.

Most research focused on ecosystems is conducted in temperate forests of North America and Europe. However, ecologists perceive the research in tropical rain forests as more and more important for comparing biomass and creating general formulae and statistical models.

Tropical rain forests play a critical role in the global carbon cycle (Cleveland, 2010). It is obvious that climatic conditions influence the process of biological oxidation, but the effect of global climate change on the global carbon cycle is obscure. The same climatic conditions that combine to maximize productivity also promote high C losses via soil respiration (Raich and Schlesinger, 1992). It proves that the basic research on soil respiration in tropical rainforest has significant importance for increasing the knowledge about the mechanisms of the "greenhouse effect".

The aim of this study was to determine the effects of altitude and slope aspect on the soil respiration rate in the low mountain cloud forest. The research was supposed to show the influence of basic environmental factors on the oxidation processes taking place in the soil.

Materials and methods

Site description

The research was conducted in July 2010 in Rancho Grande field station (10°20'57,3"N, 67°41'03,8"W), located in the northern part of Venezuela, 20 km from Maracay, in mountainous tropical cloud forest. The station is situated on the southern slope of *Cordillera de la Costa* in the Henri Pittier National Park. All samplings were done in the low mountain cloud forest (*Selva nublada de transición*). The average annual temperature at the station is ~20°C with the precipitation of 1670 mm. During the short dry season (between January and March) 20-25% of the species of trees defoliate. 150 species of plants occur on our study area of 0.25 ha (Beebe and Crane, 1947). Our main goal was to compare the respiration rate on two slopes with different aspects (Fig. 1). The sampling was done on comparable elevations (every 50 m of altitude), but in a slightly different place each time. For the first transect we have chosen the south-west slope of *La Cumbre* and the other was the north-east slope of *Pico Periquito*. Because of restricted time and conditions in the National Park, it was only possible to collect soil samples from the altitude from 1150 meters to 1400. Samples were collected also from *Atta* nest (10°20'54.9"N and 67°41'09.7"W) located in the forest below the road connecting Ocumare de la Costa with Maracay and from areas directly near the road (Fig.1). To compare the results we also did sampling on the cocoa plantation in Ocumare de la Costa (10°27'06.9"N and 67°46'22.9"W), which is situated on the northern slopes of the *Cordillera de la Costa*.

Sampling

During one week, samples were collected from Cumbre (odd days) and Periquito (even days). Samples were collected every 50 meters of elevation; from each site, 3 independent samples were taken. Additionally, we were collecting 3 samples each day from the roadside. We also gathered 13 samples on one occasion (on the 15th of July) from the cocoa plantation in Ocumare de la Costa. Additionally we took 10 samples from the *Atta* nest. Altogether, we collected 128 samples. Accidentally, 3 samples were destroyed, so they could not be used in the laboratory analysis. Finally, we used 125 samples for the statistical analysis.

The elevation for particular sites was recorded with a GPS device (Garmin). Before taking a soil sample, a superficial layer of leaves was removed to excavate the humus. Each time the soil temperature was measured by the simple soil thermometer. All samples were gathered with a little spade and placed in plastic jars of 150 ml volume, then the samples were transported to the laboratory.

Laboratory work

In the laboratory the samples were acclimatized for about 30 hours in order to achieve similar temperature and humidity conditions in all soil samples. Then, each sample of approximately 50 g of fresh soil was put into half litre glass jars. Smaller glass jar filled with 5 ml of 0.2 M

NaOH was put inside to absorb CO_2. After incubation lasting for 24 hours, the jars were opened. Then 2 ml of $BaCl_2$ and one drop of fenoloftaleine was added to NaOH.

The liquid was neutralized with use of 0.1 molar HCl, which was poured into the jar in an amount enough to change the colour from pink to milky white. The exact amount of the HCl was precisely measured, noted and then used for further calculations. Each time two blind experiments (jars without soil, but with the same procedure as for the sample) were also examined.

Data analysis

The respiration rate was calculated according to the formula by Niklińska et al. (2005), modified as follows:

$$R = 1200 \cdot \frac{(X_{SL} - X_i)}{t \cdot m_i}$$

R - respiration rate [μg CO_2/g of soil/day]

X_{SL}- the amount of 0,1 M HCl used for the neutralization of the testing sample [ml]

X_i – the amount of 0,1 M HCl used for the neutralization of the sample [ml]

t – time of incubation [days]

m_i – the weight of the sample [grams]

Two factor ANOVA was used to check the statistically significant differences between particular sites. After comparing the results to the field observations, the samples collected at the elevation of 1350 meters above the sea level on the Cumbre transect were excluded as an outlier. In that place we observed extremely different soil structure, and the results obtained were significantly different to the other sites. To compare the respiration rates on the two opposite slopes we used the simple ANOVA. The change of the respiration rate with altitude was tested with linear regression analysis, where the predictor was the elevation above the sea level. A similar analysis was used to check the relationship between the soil temperature measured in the field and the elevation above the sea level. In order to compare all sites together, the ANOVA analysis was used with a HSD post-hoc test.

All calculations were done with the aid of Microsoft Excel 2000 and Statistica 9.0.

Results

Two factors ANOVA proved the significant influence of the interaction between the slope aspect and the elevation on the respiration rate (F(5.77) = 4.01; p = 0.003). Due to the field observations and the diagram analysis (Fig. 2) we decided to exclude from further analysis the site on the Cumbre transect at 1350 meters above the sea level. After excluding that site we did not find statistically significant influence of the factors or their interaction on the respiration rate (F(4,69) = 1.46; p = 0.225) (Fig. 3). ANOVA did not indicate differences between two opposite slopes (F(1.78) = 0.31; p=0.58). ANOVA for all sites showed a statistically significant influence of site factor (F(4.120) = 7.18; p = 0.0000) (Fig. 6).

The temperature of the soil was decreasing with the increasing elevation in both transects (Fig. 5). ANOVA analysis did not show any significant differences between the transects ($p = 0{,}31$).

The average respiration rate in our plot amounted to 704.9 µg CO_2 g^{-1} fresh soil day^{-1}, but the high variance in the data should be considered. The mean values for different sites varied from 228.2 µg CO_2 g^{-1} fresh soil day^{-1} on the cocoa plantation to 916.1 µg CO_2 g^{-1} fresh soil/day in the neighbourhood of the Atta nest (Tab.1).

The *post hoc* analysis indicated differences between cocoa plantation and Cumbre transect, Perquito transect and Atta nest (Tab. 2).

Discussion

The idea of measuring the respiration rate is not new - the history of this kind of research started nearly 100 years ago. The earliest research on the soil respiration, the emission of CO_2 from the soil surface, was conducted in the beginning of the 20th century (Gainey, 1919). Nowadays, the total global emission of CO_2 from the soil is considered as one of the largest fluxes in the global carbon cycle, and even small changes in the magnitude of soil respiration could have a large effect on the concentration of CO_2 in the atmosphere (Schlesinger and Andrews, 2000). The greatest rates of soil respiration are found in the tropics, where plant growth is luxuriant and the conditions are ideal for decomposers (Schlesinger and Andrews, 2000). From this point of view, but not only, the Tropical Mountain Cloud Forests (TMCFs) are very interesting. Some evidences show that TMCFs have low primary productivity (Bruijnzeel and Veneklaas, 1998; Waide et al.,1998), little is known about carbon pools and budgets in these ecosystems, and even less information is available about soil respiration in TMCFs (Campos, 2006; Cavelier and Penuela, 1990; Priess and Folster, 2001).

Kane (2003) in his paper mentioned the statistically significant influence of the temperature on the respiration rate and, further, the influence of the slope aspect and soil temperature on the respiration rate. The results of our research did not indicate such relations. We suspected that it happened because of the very small amount of solar radiation that reaches the surface of the soil in the tropical mountain cloud forest. Even more important seems to be the fact that near the equator in the time we conducted the research, the sunlight on the slopes was more or less equal.

It is impossible to compare our result to other papers because of differences in methods and equipment used for measurements. We can still discuss environmental factors influencing this process. The climatic conditions mentioned before can be also discussed from another point of view. Tropical mountain cloud forest is an ecosystem that is frequently immersed in fog, which may bring extra water and nutrients through the so called "occult deposition" (Dawson, 1998, Chang at al., 2008). We did not check the influence of fog on the respiration rate. Our main reason for acclimatizing samples in the laboratory was to create similar conditions for all samples. Despite the stability of the weather conditions in the tropical mountain cloud forest, each day slightly different conditions could be observed.

The effect of rising global air temperature on the overall soil respiration is still a subject of debate. Some authors suggest an increasing release of soil carbon to the atmosphere (Kirschbaum, 1995). In our research we did not study directly the influence of the temperature on the soil respiration rate.

There are various methods of measuring the respiration rates: the open-flow infra-red gas analyser method (OF- method), the close chamber method (CC-method), the dynamic closed chamber method (DC-method) and the alkali absorption method (AA- method). The accuracy and sufficiency of each of them has been studied (Bekku at al., 1997). The results showed that the OF, DC and CC-methods are more suitable and the results are more comparable but the alkali method is the easiest way to measure CO_2 absorption and is the cheapest method as well (Bekku at al., 1997). That is the reason why we decided to use this method. In most known papers it is obvious that the results refer to the amount of dry soil. We did not have equipment to dry the samples at 105°C, so we refer in our results to the amount of fresh (moist) soil, which certainly influenced final results of the analyses.

In spite of this, we managed to prove that respiration rates differ between the two transects and, as well, significantly differ from the samples collected at the cocoa plantation. It is possible that responses of the microbial community to addition of carbon and nutrients could vary considerably among different soil types or land-uses (e.g. Arable *versus* forest), due to, for instance, differences in microbial community structure and ecophysiology (Dilly and Nannipieri, 2001). In our case the differences could result from differences in soil type: during the laboratory work the plantation samples seemed more humid and brownish. Several studies conducted in the tropics indicated that conversion of forests into arable lands is often accompanied by a significant reduction in soil organic carbon, nutrients (especially N and P), microbial biomass and activity (Srivastava and Singh, 1989, 1991). According to this, we can suppose, that samples collected at the cocoa plantation represent simply completely different soil ecosystem than the samples collected along the transects in the mountain cloud forest.

The regression formula describing the relationship between soil temperature and elevation at the study transects shows that the temperature decreases by 0.6°C for each 100 meters. It means that the soil temperature on the sea level should oscillate around 27.4°C. Those calculations indicate that our measurements are correct and are comparable to the rates published by World Meteorological Organization.

Acknowledgments

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Tables and Graphs

Tab. 1 Basic statistics for respiration rate (CO2-C/g fresh soil/day)

	N	**Mean**	**Variance**	**SD**	**SE**
Cumbre (SSE)	54	860.3	312085.0	558.6	76.0
Periquito (NE)	35	660.0	97884.3	312.9	52.9
Plantation	13	228.2	20240.5	142.3	39.5
Atta nest	10	916.1	212736.3	461.2	145.9
Road	13	494.9	27510.1	165.9	46.0
All	**125**	**704.9**	**223417.0**	**472.7**	**42.3**

Tab. 2 Differences between transects calculated by HSD test (red colour – p-values < 0,05)

	Cumbre	Road	Periquito	**Plantation**
Cumbre				
Road	0.054			
Perquito	0.211	0.764		
Plantation	**0.000**	0.516	**0.021**	
Atta nest	0.996	0.146	0.466	**0.002**

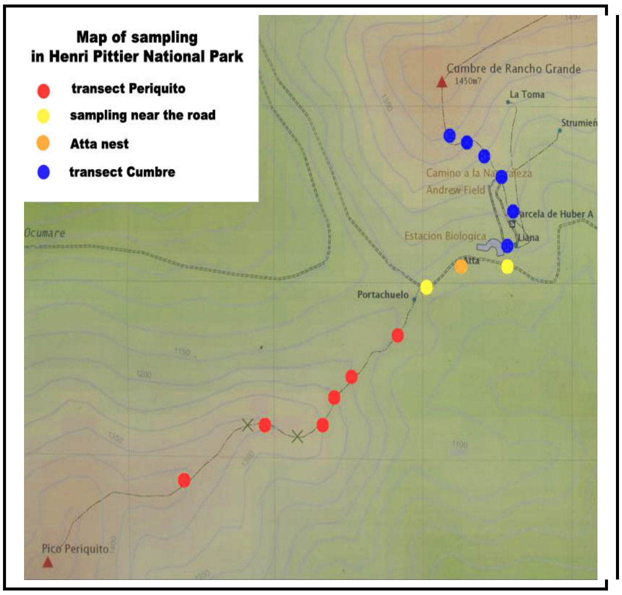

Fig. 1 Map of sampling in Henri Pittier National Park (The slope aspect of Perquito transect NE; the slope aspect of Cumbre transect SSE)

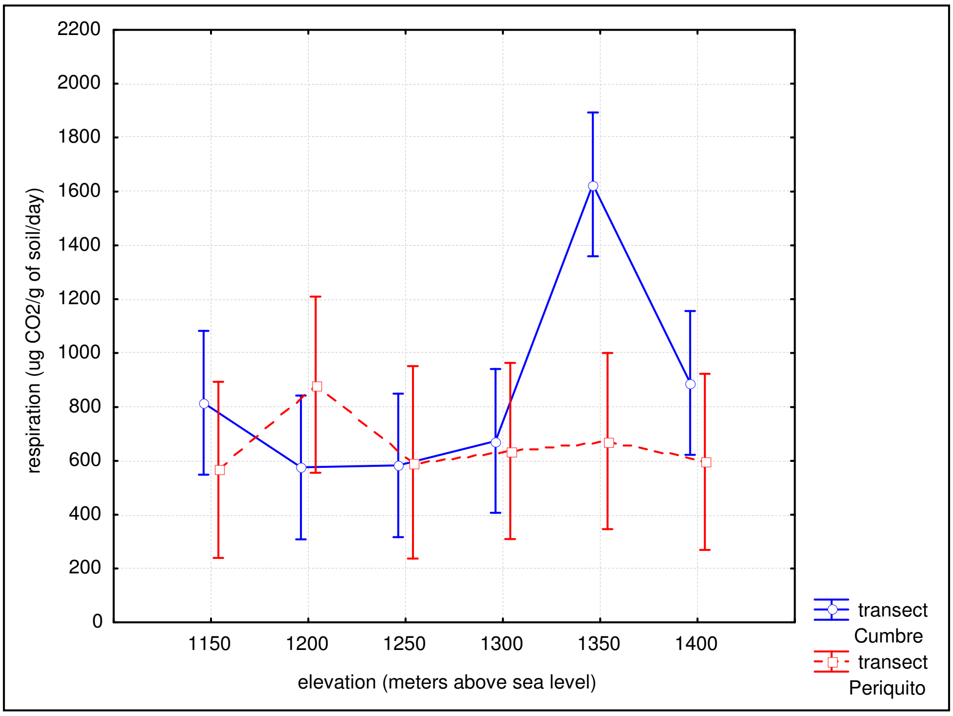

Fig. 2 Effect of the elevation on the respiration rate (means and 0,95 confidence intervals) – ANOVA analysis (in the box: effect of interaction of both factors) (The slope aspect of Perquito transect NE; the slope aspect of Cumbre transect SSE)

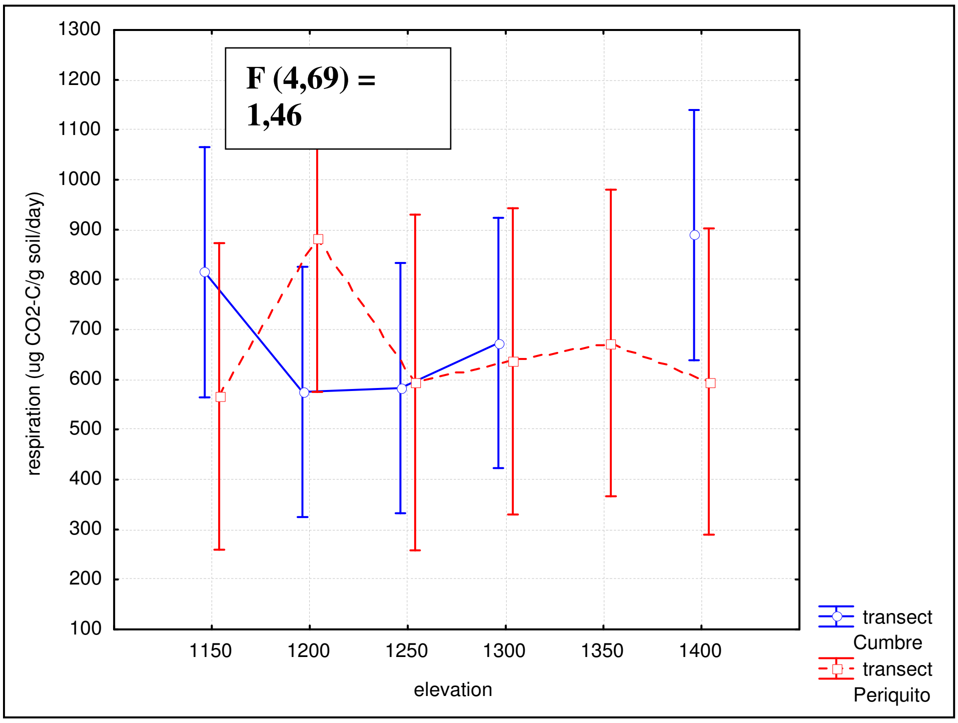

Fig. 3 Effect of elevation on respiration rate, after excluding place "Cumbre 1350" (means and 0,95 confidence intervals). In the box: effect of interaction of both factors. (The slope aspect of Perquito transect NE; the slope aspect of Cumbre transect SSE)

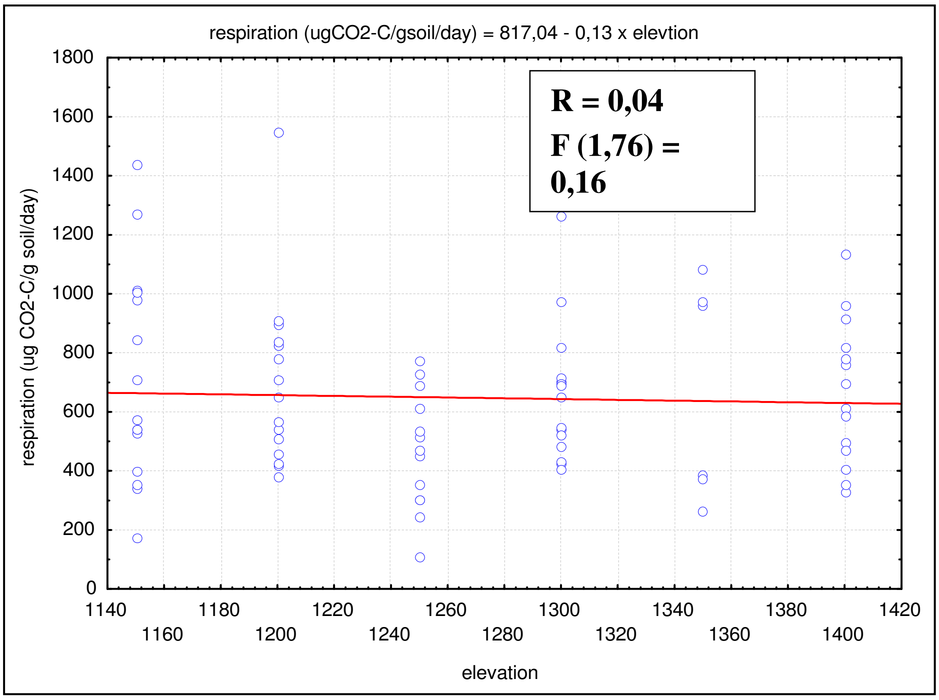

Fig. 4 Effect of elevation on the respiration rate – regression analysis

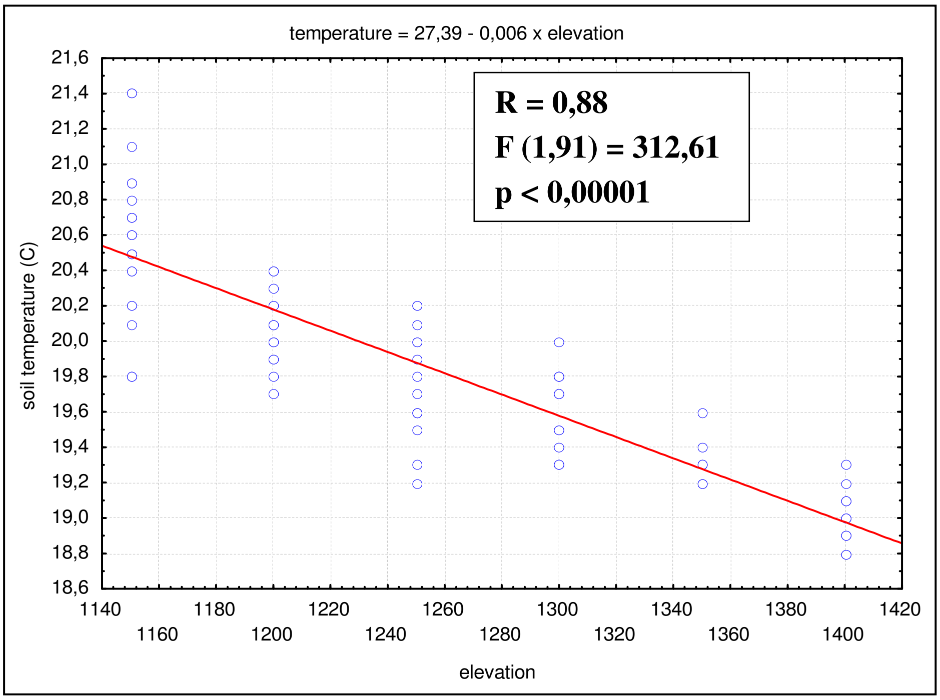

Fig. 5 Effect of elevation on the soil temperature

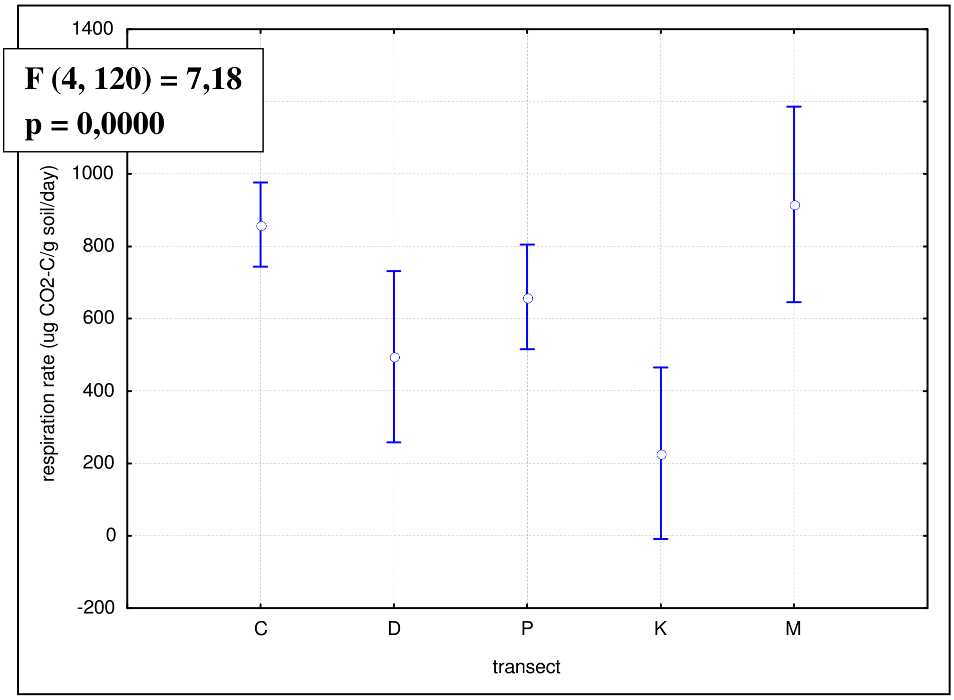

Fig. 6 Effect of environmental conditions on respiration rate (C – Cumbre, D – surrounding road, P – Perquito, K – coco and banana plantation, M – Atta nest; means and 0,95 confidence intervals) (The slope aspect of Perquito transect NE; the slope aspect of Cumbre transect SSE)