The impact caused by the introduction of a pine forest in the arthropod's fauna of a tropical savanna and its consequences

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Abstract

The introduction of a huge (500,000 ha) *Pinus caribea* plantation drastically modified the insect fauna of the original savanna ecosystem. The effect was due to a gradual replacement of the original savanna vegetation by the pines. All savanna plant species were eliminated either by shadowing or by the accumulation of a heavy acid litter layer (pine aciculae), over 1500 g/m2 dry weight. The result was the local extinction of some arthropod's groups and huge increments in the abundance of others. After five years of the harvesting of the pines, the savanna seems to be still very far from total recovery. It is estimated that, if recovery finally takes place, will require a period of more than twenty years.

1 Introduction

During the last twenty five years the Corporación Venezolana de Guayana CVG), has developed a huge plantation of *Pinus caribea* in the area of Uverito, Monagas State, north of the Orinoco River. The plantation covers over half a million hectares of an area formerly occupied by *Trachypogon* savannas, which are the climax vegetation for this zone. It may be considered as an economic success because it has transformed these savannas with little agricultural value into a very productive forest which supplies an important amount of wood and fiber for the paper industry. However, no assessment has been made of the impact that this

huge monospecific forest may produce on the fauna of the natural savanna ecosystem. This paper presents a first evaluation of the impact of the plantation on the arthropod's fauna of these savannas. It is the result of a conjoint study between scientists of the Universidad Central de Venezuela and the Universidad Autónoma de Barcelona (Spain).This project was financed by the ISC Program of the European Commission (Contract CI1*-CT 94-0099 VE).

2 Methods

2.1 Study sites

The area has a typical savanna climate, with high temperature (28 °C), moderate rainfall (1200 mm/year), and well defined rainy (May - November) and dry (January - March) seasons. To assess how the pines affected the arthropod's fauna and how it recovered after their harvesting, seven sites were sampled between June 1996 and June 1997. Their main characteristics are listed below.

S1 (Savanna 1); a natural unaltered savanna dominated by *Trachypogon vestitus.* It is the first of two savannas used as a baseline for the assessment of the changes introduced by the pine plantation.

S2 (Savanna 2, Island); a natural unaltered *Trachypogon vestitus* savanna, with an area of five ha, completely surrounded by tall pine plantations. We hypothesize that this isolation may produce the local extinction of some plant or insect species, and that the surrounding trees may act as a barrier interfering with the recolonization process from the natural savanna.

S3 (Savanna 3). This is also a natural savanna, but dominated by *Axonopus canescens.* It will be used as a complementary baseline for **S1**. Its floristic composition, biomass, and other characteristics are different from the S1 site.

P1 (Pine 1). A pine plantation 4 years old. The trees are only 3-4 m high and very sparse, allowing good penetration of light. Most savanna species survive in the patches of soil that remain between the trees, but the floristic composition is somewhat altered by a light mechanical treatment which was applied to the soil ("rastreado"), before planting the seedlings. This "rastreado" allowed the entry of some weeds and invasive species, which made the flora more diverse.

P2 (Pine 2). A mature pine forest 12 years old. Trees are about 10-12 m high, and the canopy is so dense that there is no direct sunlight penetration to the soil. There is a heavy litter layer, made mostly of pine aciculae and small twigs, reaching biomass over 1500 g/m2. The stand is completely monospecific.

P3 (Pine **3).** An area were the pines have been recently harvested. Only some dead trunks and branches remain over the soil. In this area a very fast colonization process took place during this study.

P4 (Pine 4). An area with the same history of P3 but four years older. It is now covered by a high variety of invasive plants. Although some savanna species are present, it seems that the community will need a long time to recover.

2.2 Sampling

2.2.1 Vegetation

Vegetation was sampled bi-monthly at each of the seven sites to determine its richness, floristic composition, the relative abundances of the species; and the total, green and dead biomass. This was achieved by means of: 1) Fifteen 1m2 random quadrats (25 for the P3 site) in each savanna, where all plant species were identified and their cover was visually estimated. 2) Five 1/4m2 quadrats in each savanna were used to estimate, by harvest methods, the biomass and green/dead ratio.

2.2.2 Insects

This sampling was performed monthly. For each site we set: a) 10 Pitfall Traps, left in the field for 30 days; b) 6 yellow plates, three at 40cm high and 3 at 1.5m high, left in the field for 2.5 days; c) 1000 sweeps, divided in four series of 250 sweep each, made with a hand net 40cm diameter, walking at random through the site; d) 1 Malaise Trap, left in the field for 2.5 days. Ten biocenometer samples 1/4 m^2 each where set during the first sampling date in each savanna, but rendered a small number of insects and the method was judged impractical.

3 Results

Due to the limits imposed to the length of this paper, we will ignore here all seasonal variations and will focus only in the month of June, when the highest abundance of insects was recorded.

3.1 Vegetation

Table 1. The values of several vegetation variables for six of the seven sites under study. Total # of spp. is the total number of species found in 15 m2 (25 m2 for P3). Spp. per m2, is the mean richness per 1 m2 or "density" of richness, Magurran[3]. % of total, is the proportion of the total flora of the savanna that appears in a single sample. It is a measure of the spatial homogeneity of the community; the larger its value, the more homogeneous is the floristic composition of the different samples.

	Savanna					
	S1	S2	S3	P1	P3	P4
Biomass (g/m2)						
Total	584.3	612.2	520.0	553.3	38.4	736.6
Green	318.8	252.1	222.9	245.9	31.4	338.4
Green/dead	1.20	0.70	0.75	0.80	4.5	0.85
Cover (%)	62.3	57.3	50.3	65.3	1.2	80.7
Total # of spp.	21	30	19	37	7	17
Spp. Per m^2	7.5	7.5	4.6	9.1	0.9	2.9
% of total	35.7	25.0	24.2	24.6	13.1	17.2

Table 1 gives the values of some vegetation variables. The P2 site is not included because it is a monospecific stand of *Pinus caribea*. From this table we may see that:

1) All savannas (except P3 and P4) have similar biomass values, that are in the same range of other *Trachypogon* savannas of Venezuela, Bulla[1], Zuccaro & Bulla[6]. P3 (the recently harvested pine plantation) has very low biomass and cover. P4, the successional area 4 years old has the highest primary production.

2) There is a high proportion of dead material in these savannas, due to the absence of fire (they are protected against fire to prevent its spread to the plantation). P3 is the only one with a predominance of green material.

3) Both the *Tachypogon* and the *Axonopus* baseline savannas (S1 and S3) are similar in their total number of species. The island savanna (S2) has 30% more species, a opposite tendency to what we were expecting as a result of the isolation.

4) Concerning the "pine" savannas, P1, the pine plantation 4 years old is the richest with 37 species. This savanna also has the maximum number of species per m2. Very interesting is the case of the two successional savannas (P3 and P4). As expected, P3 has a very low richness with only 7 species. P4, after four years of recovery, has only 17 species, but has the highest biomass. This is less than half the number of species found in P1, the plantation 4 years old.

3.2 Insects

The way in which the data for the insect community were collected allowed us to assess the effect of the pines on three different fractions of this system.

a) the fraction of the insects that fly over the "canopy" of the vegetation and are captured (selectively) by the yellow plates; b) the fraction in the upper layers of the vegetation, captured by the sweeps; and c) the fraction associated to the litter or wandering over the soil, captured by the pitfall traps.

Even ignoring the temporal variation, the amount of information produced by these three method is so huge, that we decided to summarize it in three diagrams; each one representing the behavior of one part of the system (figure 1,2,and 3). The diagrams integrate the seven study sites in a single cycle of change. Each savanna represents a state of this cycle. In each diagram the squares represent the sampling sites with their main characteristics, and the connecting lines provide information about the processes we believe rule the change from one state to the other. We begin with the yellow plates.

3.2.1 Yellow plates (Moericke traps)

The total number of individuals captured in the month of June was 4366, but the total abundances differed broadly among the different savannas. The richest one (surprisingly) was P2, the mature pine forest with 1025 individuals; the poorer was the ***Axonopus*** savanna (S3) with 328. These differences among sites are due mainly to the order Diptera. If this group is excluded the richest savanna is S1, the natural *Trachypogon* savanna with 422 individuals and the poorest P3 with 195 (but S3 has 198 individuals). P2 has 320 non-diptera individuals. Consequently,

this type of sample is strongly dominated by this order, which is always between 40 and 70% of the total sample. The more important families are Dolichopodidae Clorophidae and Chironomidae. The way in which the abundances of the different groups change in comparison with the natural savannas used as a baseline is illustrated in figure 1.

3.2.2 Sweep samples

It was not possible to use this collecting method in two savannas; P2, the mature pine forest and P3 the early successional savanna. In the first case, there is no vegetation under the canopy; in the second, the soil was almost completely bare

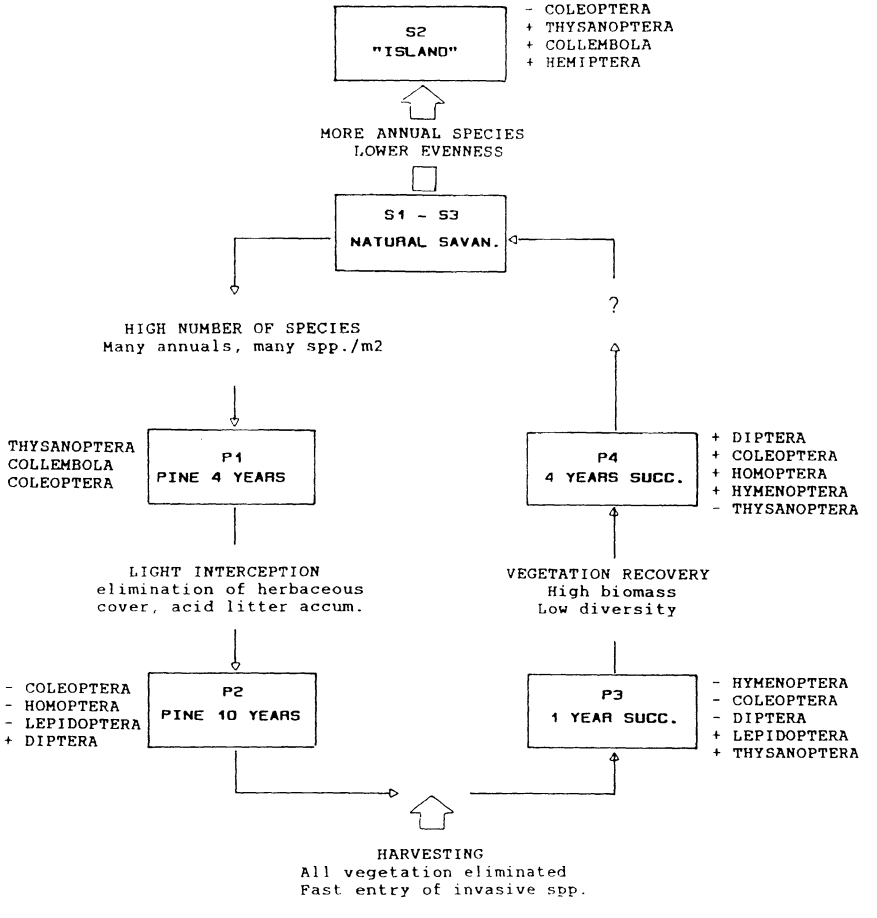

Figure 1: A diagram illustrating the main changes that take place in the insect fauna captured by the yellow plates, along the cycle of pine planting, harvesting and recovery of the original savanna.

during June. Consequently, this first analysis will be restricted to five savannas. In all cases the total number of individuals captured in each savanna is remarkably homogeneous. P1 and P4 had 600 and 632 individuals. The three natural savannas have 441, 451 and 302 specimens. The dominant group was Hymenoptera in all sites, with abundances ranging between 271 (S1) and 102 individuals (S2). the Orthoptera rendered a total capture of 22, 38, 27, 127 and 23 individuals for S1, S2, S3, P1 and P4 respectively. This group was very abundant in P1. The Homoptera (mainly Cicadellidae) had between 79 (S2) and 41 (S1) individuals, quite similar in the five savannas. S2 (the island savanna), is similar to P1 (the plantation 4 years old), a fact that will be discussed later.

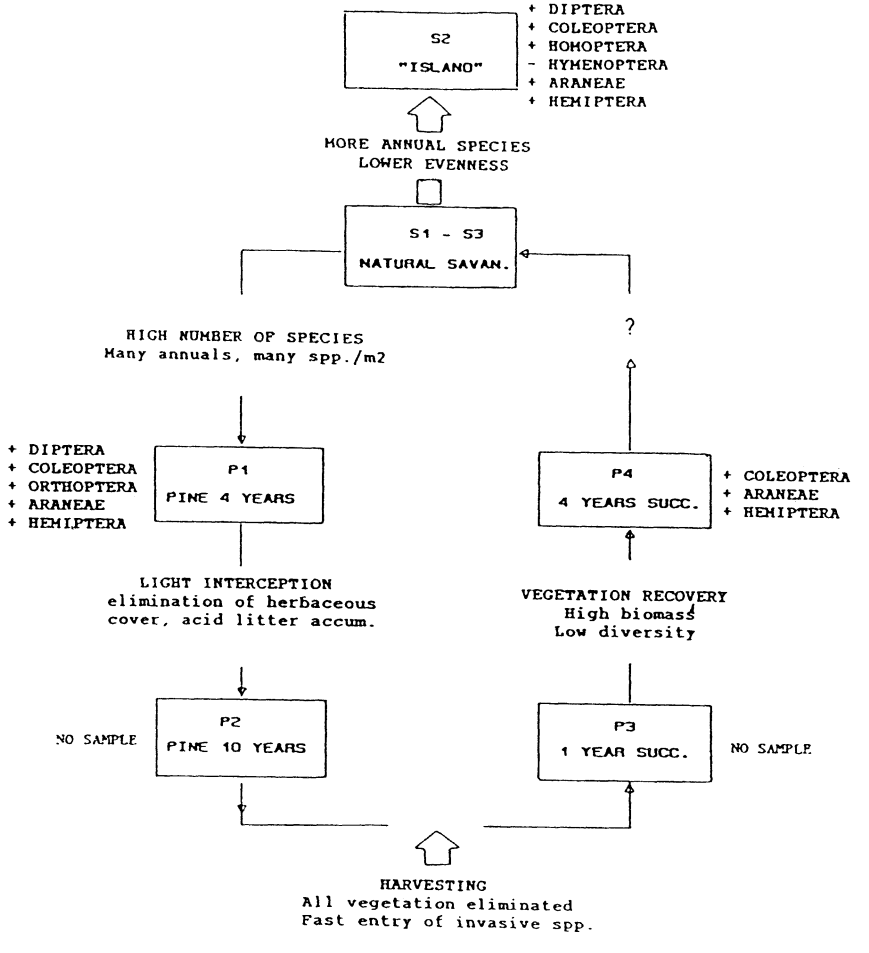

Figure 2: The changes in the insect fauna captured by the sweeps, along the cycle of pine planting, harvesting and recovery.

3.2.3 Pitfall traps

A wide variety of animals were captured in these traps; including toads, lizards, mice and other vertebrates, but we will restrict our report to the invertebrate fauna. During the month of June, a total of 58000 specimens were collected by the 70 traps located in the seven savannas. Only the most outstanding facts of this complex data matrix can be shown in this section. a) The total number of specimens captured in each savanna, varied between 2005 in P1 to 29707 (15 times higher) in P3. These huge differences are due to the behavior of two groups; Acarina and Collembola. If they are omitted from the analysis total abundances range between 1599 individuals (P2) and 4593 individuals (P4). b) The nine more

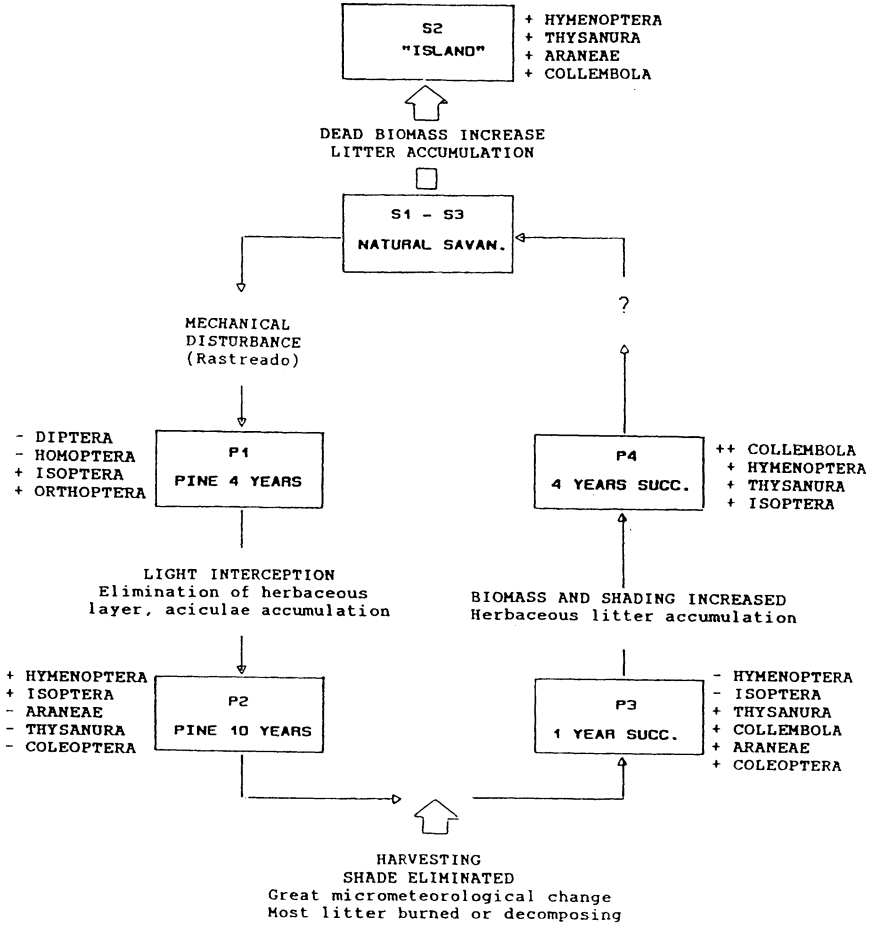

Figure 3: The main changes in the arthropod fauna captured by the pitfall traps, along the cycle of pine planting, harvesting and recovery of the original savanna.

abundant taxa are Araneae, Coleptera, Chilopoda, Diptera, Homoptera, Hymenoptera, Isoptera, Orthoptera and Thysanoptera. The dominant orders are Coleoptera, Diptera and Hymenoptera (mostly ants). The Araneae are very abundant in many cases. The changes in the relative abundances of these groups in the different savannas may be appreciated in figure 3. c) Several other taxons occur with very low abundances (less than 0.1% of the sample) like the Dermaptera, Dyctioptera, Lepidoptera, Myriapoda, Oligochaeta, Pseudoescorpionida, Psocoptera, Solifuga and Thysanoptera. d) The three natural savannas are quite similar in comparative terms, while the four pine savannas are quite different. P1 and P4, have high abundances of Coleoptera and Orthoptera, and P4 has very high numbers of Hymenoptera and Isoptera. P3 the early successional savanna, is characterized by low abundances of Isoptera, Homoptera and Hymenoptera, but the highest values of Chilopoda, Thysanura and Araneae. Finally P2, the mature pine forest, has a high number of Hymenoptera (mostly ants), and Isoptera, but lacks Orthoptera and Thysanura and has low values of the other orders.

4 Discussion

From the information presented above we derived certain hypothesis about the way in which the pine plantation affects the natural savanna. Before presenting them, it is important to emphasize that each plantation is a cycle that begins with the preparation of the soil and continues with the planting, the gradual growing of the trees, the harvesting, and the recolonization of these areas by the herbaceous vegetation. This last step presumably closes the cycle and returns the savanna to its original condition. The seven study sites are selected points of this complex cycle; that we will try to describe in the following section with some detail.
A second effect of the pine plantation is the creation of savanna "islands". In the planting process, some areas are not cultivated, and remain isolated into the forest, behaving as islands of savanna in a sea of pines. The consequences of this isolation (shown in the S2 site), will be discussed in the second part of this section.

4.1 The cycle of planting-harvesting and recovery

1). The first interesting effect of the pine plantation, that may be observed in P1, is a significant increase in plant diversity. We think that this is due to the application of a light mechanical treatment to the soil (called "rastreado"), prior to the planting. This "rastreado" eliminates part of the vegetation cover, with the purpose of minimizing competition between the young pine seedlings and savanna plants; but at the same time gives the opportunity to many invasive species to establish in the gaps. The "rastreado" is done just before the beginning of the rainy season, a few days before the planting of the pines. This gives to the very fast developing invasive species a unique opportunity of growing in an almost competition-free environment, without interference with the savanna species. The dominant savanna plants are perennials that grow in the middle of the rainy season at a much

slower rate, Sarmiento[4]. Given these conditions the invasive species become easily established in the community. This enrichment and change in the floristic composition has a clear effect in the insect fauna captured by the sweeps and yellow plates. There is an increase in the abundance of Orthoptera, Coleoptera, Diptera, Hemiptera and Thysanoptera. Also the Araneae increase, perhaps due to the presence of more potential preys.

2) As the pines grow, they gradually eliminate all other plant species; either by shadowing (that greatly affects the heliophylus savanna species) or by the accumulation of a heavy acid litter layer over the soil. The result is the complete elimination of all vegetation under the tall pines of P2. In this simplified system, with few resources, many savanna insects suffer an important drop in their abundances or disappear. More notoriously, the Orthoptera, Homoptera, Coleoptera, Lepidoptera, Thysanura and others decrease but the Hymenoptera (specially ants) and Isoptera become dominant, together with some groups of Diptera. Ants are able to use eficiently the pine acicules, and constitute one of the greatest economic problems in these pine plantation.

3) The next step is harvesting. All pines are removed and the twigs and trunks remaining in the area are burned. The result is a bare area, with no vegetation at all and only some litter left over the ground. After that, a very fast colonizing process takes place, as was observed in P3. However, the first colonizers are not the dominant plant species of the natural savanna, but annuals of little importance in the climax community. These species reach in P3 a dominance they never achieve in natural conditions and interfere with the recovery of the original savanna vegetation. A few months after the harvesting the first insects to appear are Lepidoptera, Thysanoptera and Orthoptera, but also some ants and Isoptera survive the catastrophe and remain in the place.

4) Four years later we found in the area a plant community that, although it has some characteristic savanna species in its composition, is quite different from the climax one (S1 and S3). It is less diverse, with higher productivity and dominated by weeds and invasive species. This fact may be due to two "residual" effects of the pine plantation; a) as mentioned before, it may exist a residual deleterious effect of the acid litter layer that precludes the entry of some savanna species; but besides, b) The pines may produce an indirect fertilization effect over the soil. This last point deserves some explanation. When the pines are harvested, only the aerial part is removed. A huge amount of dead roots remains into the soil and gradually decomposes liberating some amount of nutrients and fertilizing the soil. This fact may explain why P4 has the highest primary production of all sites. The problem is that many savanna species are adapted to very poor soils. In richer conditions they are unable to compete with the more nutrient demanding invasive species. Some experiences indicates that in this enriched soils they will never displace them, Candia[2] . Consequently, the future of this altered system remains uncertain. Either these nutrients will be washed away by the rains and the savanna species will have a chance of re-enter the system, or they will stay there and the invasive vegetation will remain. Only careful monitoring over a long period of time may answer this question.

4.2 The island effect

Our original hypothesis about S2, the "island" savanna, was that its isolation will produce a gradual extinction of animal and plant species. Facts indicate that we were completely wrong!. Instead of a poorer, we found a richer savanna than the natural ones. This savanna, both in insects and plants composition, approaches more P1 (the four years old plantation) than any other of the study sites. The explanation of this phenomenon is simple; S2 doesn't work as an island, works as a refuge. When the pines that now completely surround it began to grow, this area had the community structure of P1. When the forest increased its size and the plants and insects of the savanna were gradually displaced, there was only one place were they can survive, the island of savanna that remained in the middle of the forest. S2 acted like Barro Colorado, that when the surrounding areas begin to disappear under the water was used as a life-boat by many species. S2 is now over-saturated with species, (Simberloff & Wilson[5]), but given enough time, some extinction will take place lowering its diversity. Although it has not been presented here, there is strong evidence that extinction is taking place in S2. The "island" savanna has a large amount of very rare species, that appear only on one or two samples, indicating that they are in precarious condition and may become locally extinct. However, this may never happen, because the pines surrounding these area are ready for harvesting and its island condition will promptly disappear.

5 References

1. Bulla, L., Relationships between biotic diversity and primary productivity in savanna grasslands, Chapter 6, *Biodiversity and Savanna Ecosystem Processes*, ed. O. Solbrig, E. Medina & J. Silva, Springer-Verlag, Berlin and Heidelberg, pp. 97-120, 1996.

2. Candia, R., Cambios en la estructuración de la comunidad de insectos asociados a una sucesión secundaria, Dissertation, Facultad de Ciencias, Universidad Central de Venezuela, 1997.

3. Marrugan, A. E., *Ecological Diversity and its Measurement*. Princeton University Press, Princeton, 1988.

4. Sarmiento G. *The ecology of Neotropical Savannas*, Harvard University Press, Cambridge, 1984.

5. Simberloff, D. & Wilson, O., Experimental zoogeography of islands: the colonization of empty islands. *Ecology* ,**50**, p.p. 278-289, 1969.

6. Zuccaro G. & Bulla, l., Estudio comparativo de la entomofauna de cuatro sabanas venezolanas. *Acta Científica Venezolana*, **36**, p.p. 365-372, 1985.