ARTHROPODS OBTAINED FROM THE AMAZONIAN TREE SPECIES "CUPIUBA" (*Goupia glabra*) BY REPEATED CANOPY FOGGING WITH NATURAL PYRETHRUM

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ABSTRACT — Two canopies of a widely distributed Amazonian tree species, *Goupia glabra* Aubl. (Celastraceae, height 38 and 45m) were fogged several times with 1% natural pyrethrum during the rainy and dry seasons (1991-1994) in the Adolpho Ducke Forest Reserve near Manaus/Brazil. Between 50 and 158 ind./m^2 of arthropods were obtained per tree and fogging event. Hymenoptera, mostly Formicidae, and Diptera dominated. A total of 95 ant species occurred on a single tree. Most ants were permanently foraging in the canopy and their recolonization after fogging seems to follow stochastic pathways. Data indicated an interaction between -1) predating Formicidae and gall building Cecidomyiidae and -2) Cecidomyiidae and the parasitic Hymenoptera.

Key words: Canopy fogging, pyrethrum, arthropods, recolonization, interactions, Amazon, Neotropics.

Artrópodos Obtidos Através de Nebulização Repetitiva da Copa de uma Árvore Amazônica, "Cupiuba" (*Goupia glabra*), com Piretróiide Natural.

RESUMO — Duas copas de uma espécie de árvore amplamente distribuida na Amazônia, *Goupia glabra* Aubl. (Celastraceae, altura 38 e 45m) foram renebulizadas várias vezes com píretro natural 1%, durante o período chuvoso e seco (1991-94) na Reserva Florestal Adolpho Ducke próximo de Manaus/Brasil. Entre 50 e 158 ind./m^2 de artrópodos foram obtidos por árvore e evento de nebulização. Hymenoptera, na sua maioria Formicidae, e Diptera dominaram. Um total de 95 espécies de formigas ocorreram numa única árvore. A maioria das formigas estava permanentemente forrageando na copa e a sua recolonização depois a nebulização parece seguir vias estocásticas. Os dados sugerem uma interação entre Formicidae e Cecidomyiidae (construindo galhas) e Cecidomyiidae e Hymenoptera parasítica.

Palavras-chave: Nebulização de copas, píretro, artrópodos, recolonização, interações, Amazônia, Neotrópicos.

INTRODUCTION

One possibility to explain the high within-community diversity of arthropods in the tropical canopy is that continuous stochastic local disturbances in nature are assumed to prevent the achievement of any long-term equilibrium (climax) state. These so-called stochastic non-equlilibrium models assume that the presence of a species at a vacant site is important. This may represent an advantage against all species that arrive later. Niche overlaps are assumed to be very common within species-rich communities. As a result, neither successional stages nor a climax community can

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emerge. This is in contrast to the so-called deterministic equilibrium models which are based on the ecological niche. Each organism maintains a defined position in its environment and, driven by competition, the system runs through defined successional stages and ends up with a structurally predictable climax equilibrium (see Linsenmair (1990) for details).

The purpose of this study was to cause local disturbances and make sites vacant by refogging the canopy of a widely distributed Amazonian tree species. Data allow a first insight into the composition and interaction of the arthropod guild in the Neotropical canopy. In particular, into the patterns and dynamics of recolonization by species of common arthropod groups. In this contribution we focus on Hymenoptera, especially the Formicidae and Diptera.

MATERIAL AND METHODS

Our study area, the Adolpho Ducke Forest Reserve ("Reserva Ducke") is covered by 90 km^2 of mostly undisturbed rainforest on terra firme latosol and is located 26 km north-east of Manaus (02°55'S, 59°59'W). It belongs to the National Institute for Amazonian Research (INPA) and represents one of the most intensively studied upland forest sites in Central Amazonia (e.g. Adis *et al.*, 1984, 1997; Hero, 1990; Höfer *et al.*, 1994; Penny & Arias, 1982; Prance, 1990; Willis, 1977).

Sampling was conducted on two specimens of the tree species *Goupia glabra* Aubl. (Celastraceae; common name "Cupiuba") which has a high local abundance and is widely distributed in Amazonian upland forests (Brazil, Colombia, Venezuela and the Guianas; Loureiro & Silva, 1968).

The first tree sampled, Cupiuba 59 (height 45m, crown diameter approximately 15m, contact to neighbouring tree canopies sporadical, no lianes nor epiphytes) was fogged with a Swingfog SN 50 two times per day in August 1991 (dry season; Ribeiro & Adis, 1984) on two consecutive days. The fogging machine was hoisted into the lower canopy on a rope and pulley system early in the morning. Release of the insecticide (Fig. 1) was controlled from the ground by radio-control. Subsequently, the fog was directed to all parts of the crown by rotating the fogger round 180° with the rope from which it was suspended (Erwin, 1983). As knockdown agent, a 1% solution of natural pyrethrum (without synergist) diluted in diesel oil was used for the first three fogging events and synthetic pyrethrum Baythroid 0.15% for the fourth fogging. The knockdown effect of the killing agent Baythroid was stated by the manufacturer (Bayer, Leverkusen/Germany, personal communication) to be 10 times more effective than that of the non-killing natural pyrethrum. After each fogging, arthropods were intercepted in 18 funnel-shaped collecting trays placed directly under the canopy. They were made of a fine, smooth nylon fabric on a metal frame (Stork & Brendell, 1990). They hung about 1m above the ground and up to 5m from the tree trunk on a web of ropes tied about head-height on available tree trunks (Fig. 2). At the end of each drop period (1 or 2 hrs), specimens were washed down the funnel

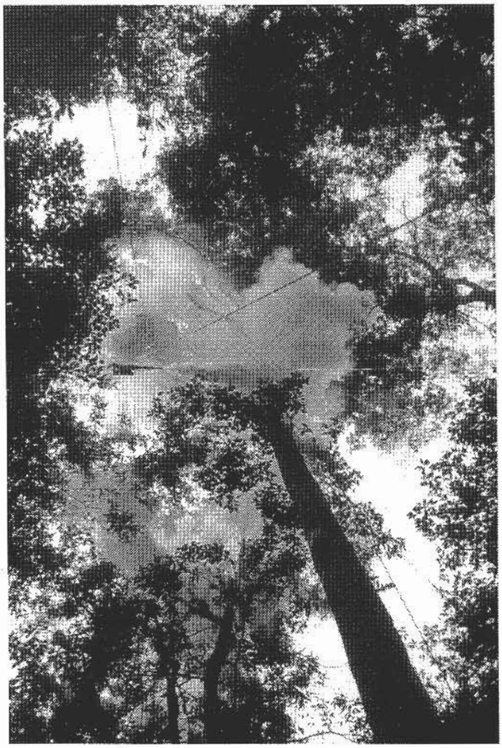


Figure 1. A cloud of natural pyrethrum fog is produced by a fogging machine at dawn and rises through the canopy of a 45m high *Goupia glabra* (Cupiuba 59; photo J. Adis).

Figure 2. Funnel-shaped collecting trays are suspended from ropes under the canopy of *Goupia glabra* (Cupiuba 59; photo J. Adis)

walls with a garden sprayer filled with 70% ethanol into plastic bottles attached to the funnel outlet (Erwin, 1989). Cupiuba 59 was refogged after 6 or 24 months with 1% natural pyrethrum (without synergist) during the rainy season (February, 1992) and the dry season (August, 1992 and July, 1994).

A second tree specimen, Cupiuba 64 (height 38m, crown diameter about 14m, contact to neighbouring trees sporadical, no lianes nor epiphytes) was fogged for the first time with 1% natural pyrethrum (without synergist) in February, 1992 (rainy season) and refogged 6 and 24 month later during the dry season (August, 1992 and July, 1994). This tree was about 1 km distant from Cupiuba 59. Further details of study site and fogging methodology are given in Adis *et al.*, (1997). Relative abundances (ind./m^2) represent the calculated mean of arthropods obtained in the 18 collecting trays which were installed below the canopy of each tree per fogging event.

RESULTS AND DISCUSSION

Between 898 and 2850 arthropods (50 -158 ind./m^2) were collected per fogging event during the dry and rainy seasons in the 18 trays installed below the canopies of Cupiuba 59 and 64 (Figs. 3, 4). Hymenoptera (51%), mostly Formicidae (45%) and Diptera (58%) dominated. The higher proportion of Coleoptera during the rainy season (February, 1992) on Cupiuba 59 was due to Chrysomelidae (12 spp.). A total of 95 ant species were obtained from the canopy of one single tree (Tab. 2: Cupiuba 59; cf. Harada & Adis, 1997). This is close to the total number of ant species recorded from Germany (n=105; Seifert, 1993).

The composition of the arthropod fauna in the canopy may differ between tree species. For example, in contrast to the results obtained from Cupiuba, the sample density of Hymenoptera and Coleoptera collected from the canopies of *Eschweilera* cf. *odora* (Lecythidaceae; height 30-35m) and *Dipteryx alata* (Leguminosae; height 30m) in the same forest reserve was higher than that of Diptera. Half the species of ants obtained from *D. alata* did not occur on *E.* cf. *odora* (Adis *et al.,* 1984).

In our study, each fogging event represented a local disturbance. The occurrence of ants in the Cupiuba canopy after fogging seems to be incidental and to follow stochastic pathways. Most of the highly mobile ants are permanently foraging in the canopy. This is indicated by the high amount of singletons and dubletons per species (Tab. 3; cf. Harada & Adis, 1997). At least 69% of them represented arboricolous species. There was evidence that ants immigrated within 24 hours after canopy fogging from neighbouring trees with overlapping canopies, from the lower trunk region, and from the forest floor (Harada & Adis, 1997). A species turnover of 50% between fogging events (Tab. 3) mainly concerned the rare species. Results are different from fogging studies in the canopy of understorey trees (3 sp.; height 28m) in a lowland forest in Sabah, Malaysia (Floren & Linsenmair, 1997a,b). Here, only few

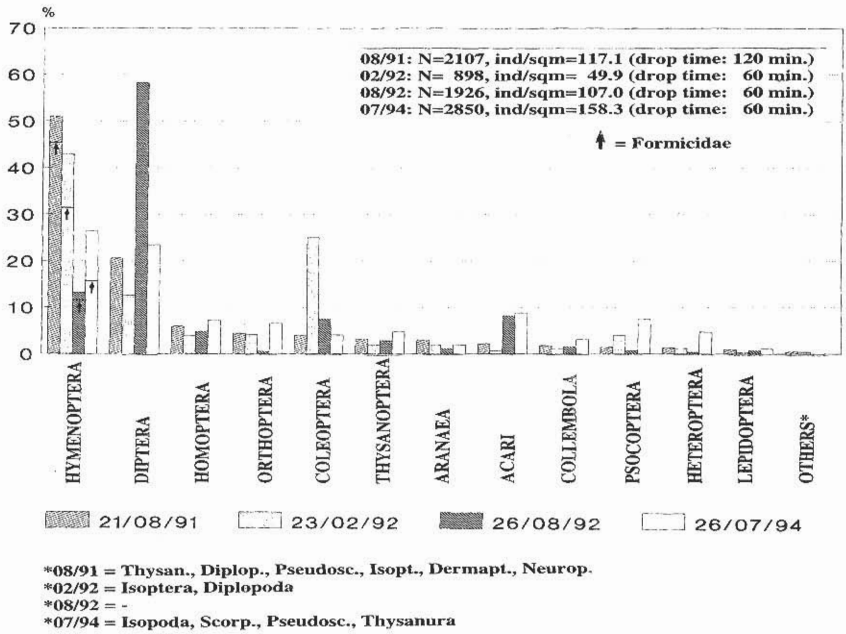


Figure 3. Dominance, total number and abundance of arthropods obtained by fogging the canopy of Cupiuba 59 (*Goupia glabra*) with 1% natural pyrethrum between 1991 and 1994 at Reserva Ducke near Manaus.

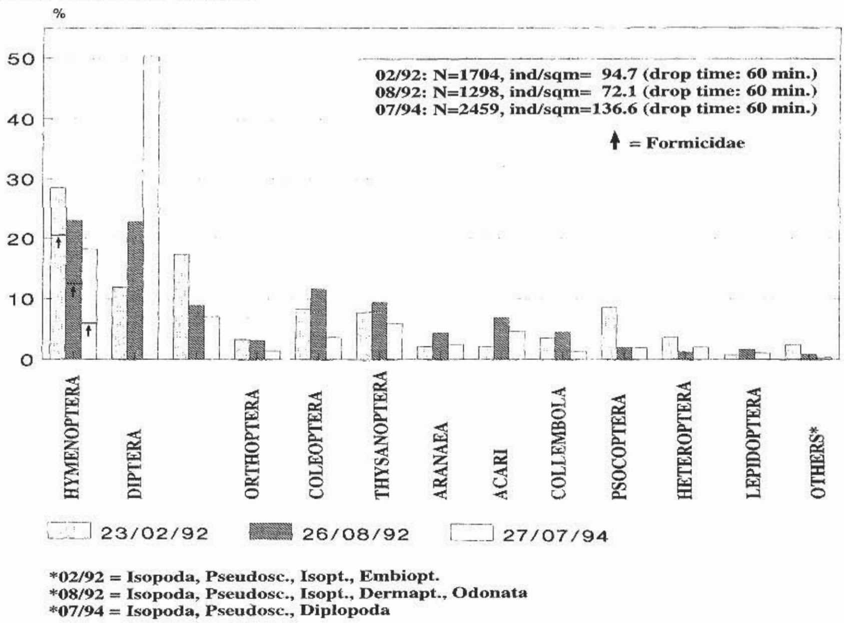


Figure 4. Dominance, total number and abundance of arthropods obtained by fogging the canopy of Cupiuba 64 (*Goupia glabra*) with 1% natural pyrethrum between 1992 and 1994 at Reserva Ducke near Manaus.

Table 1. Numbers and percentage of Diptera families obtained by fogging the canopy of two Cupiuba trees (*Goupia glabra*) with 1% natural pyrethrum between 1992 and 1994 at Reserva Ducke near Manaus.

	Cupiuba 59					Cupiuba 64					Cupiuba 59 & 64	
DIPTERA	02/92	08/92	07/94	**Total**	%	02/92	08/92	07/94	**Total**	%	**SUM**	%
Nematocera	57	1159	812	2028	92.1	100	195	1505	1800	91.6	3828	91.9
Cecidomyiidae	27	850	385	1262	57.3	50	119	766	935	47.6	2197	52.7
Ceratopogonidae	2	32	133	167	7.6	1	11	428	440	22.4	607	14.6
Chironomidae	8	89	213	310	14.1	21	14	224	259	13.2	569	13.7
Sciaridae	14	167	45	226	10.3	22	35	52	109	5.5	335	8.0
Tipulidae	–	5	7	12	0.5	–	1	18	19	1.0	31	0.7
Culicidae	1	3	5	9	0.4	–	1	4	5	0.2	14	0.3
Mycetophilidae	1	3	11	15	0.7	1	13	6	20	1.0	35	0.8
Psychodidae	4	10	13	27	1.2	5	1	7	13	0.7	40	1.0
Brachycera	41	39	94	174	7.9	37	35	93	165	8.4	339	8.1
Dolichopodidae	1	8	52	61	2.8	6	10	64	80	4.1	141	3.4
Phoridae	17	8	13	38	1.7	6	14	7	27	1.4	65	1.6
Empididae	1	8	1	10	0.5	–	–	1	1	<0.1	11	0.3
Milichidae	2	1	13	16	0.7	–	5	13	18	0.9	34	0.8
Drosophilidae	14	4	2	20	0.9	4	1	5	10	0.5	30	0.7
Others	6	10	13	29	1.3	21	5	3	29	1.5	58	1.4
SUM	98	1198	906	2202	100.0	137	230	1598	1965	100.0	4167	100.0
%	4.5	54.4	41.1	100.0	–	7.0	11.7	81.3	100.0	–	–	–

additional species were recorded after refogging of trees and most ant species represented trunk inhabitants that had survived the fogging events.

The species composition of ants in each of the two Cupiuba canopies sampled were distinct. Fifty-seven (46.0%) out of the total 124 ant species were obtained solely from Cupiuba 59 and 28 species (22.6%) only from Cupiuba 64 (data calculated from Table 17.1 in Harada & Adis (1997) and from Table 2 in this study). Adis *et al.* (1984) found 43% of the total ant species (n=21; 2580 ind.) to occur only in the canopy of one tree of *E.* cf. *odora* and 24% solely in a second tree canopy of this species.

Only 2-6 nests were obtained per Cupiuba tree and fogging event, and (re)colonization (cf. Tab. 3), i.e. nidification of ant species, was low. In the case of *Cephalotes atratus* (Tab. 2), the reason might be the presence of Membracidae (Homoptera) like *Richteria peruviana* (Funkhouser) which live in the canopy of various Neotropical tree species and produce honeydew the ants feed on (Strümpel, 1985). A low number of ant nests was also found in the canopy of Cupiuba trees at the Rio Orinoco in Venezuela, based on visual observations from a crane (Schmücke & Morawetz, personal communication).

At fogging intervals of six months, the number of ants collected decreased continuously (from 45% to 5% of the total catch), whereas the amount of Diptera (in particular gall building Cecidomyiidae; cf. Table 1) and other (mainly parasitic) Hymenoptera increased (from 12% to 58% and from 6% to 12% (except in August, 1992), respectively). This tendency was also observed after a fogging interval of two years (1992-94) if only few ants had returned to forage in the tree canopy. This was true in Cupiuba 64 (Fig. 5: bottom), where both number of specimens and species were similar in August, 1992 compared to

Table 2. Ant species obtained from two Cupiuba trees (*Goupia glabra*) at Reserva Ducke near Manaus by refogging the canopy after two years with 1% natural pyrethrum during the dry season (July, 1992). Data on ant species collected during previous fogging events are given in Harada & Adis (1997).

FORMICIDAE	Cupiuba 59	Cupiuba 64	Total	X	a	t	?
Subf. Dolichoderinae							
° *Azteca* nr. *delpini*	-	9	9	2,6	x?		
Dolichoderus diversus	1	-	1	5,1	x		
Dolichoderus lutosus	4	-	4	3,4	x		
° *Dolichoderus rugosus*	1	-	1	10,6		x	
° *Tapinoma amazonicum*	1	2	3	1,5	x?		
° *Tapinoma ramulorum*	-	3	3	1,8	x?		
Subf. Formicinae							
Camponotus abdominalis A	-	1	1	6,5			x
Camponotus alboannulatus A	1	-	1	4,8			x
Camponotus alboannulatus B	-	1	1	4,5			x
° *Camponotus brasiliensis*	1	32	33	3,2	x	x	
° *Camponotus coptobregma*	2	-	2	5,7			x
Camponotus crassus	28	-	28	3,7	x?		
° *Camponotus eurynota*	6	-	6	3,3			x
° *Camponotus femuratus*	1	-	1	4,7	x		
Camponotus nr. *abdominalis*	-	1	1	5			x
° *Camponotus luederwaldti*	2	-	2	3,1			x
Camponotus nr. *bidens*	7	23	30	3			x
° *Camponotus pittieri*	44	12	56	3			x
Camponotus rapax	-	1	1	7,9	x?		
Camponotus sp. 34	7	-	7	3,7			x
° *Camponotus sp.49*	1	-	1	7			x
Dendromyrmex fabricii	1	-	1	5,7			x
Subf. Myrmicinae							
Cephalotes atratus	129	15	144	10,1	x		
Procryptocerus goeldii	6	7	13	4	x		
Procryptocerus marginatus	15	5	20	5,8	x		
Zacryptocerus duckei	1	-	1	3	x		
° *Zacryptocerus sp. 22*	2	-	2	2,5	x?		
Crematogaster sp. 1	-	1	1	2	x?		
Crematogaster sp. 2	11	1	12	2,2	x?		
Crematogaster sp. 3	14	1	15	2,2	x?		
Crematogaster limata	3	-	3	2,7	x?		
Crematogaster sp. 7	8	-	8	2,6	x?		
Crematogaster sp. 8	-	6	6	2,5	x?		
Crematogaster sp. 9	1	-	1	2	x?		
Crematogaster sp. 10	88	9	97	1,9	x?		
Leptothorax (Nesomyrmex) sp. 2	19	1	20	1,6	x?		
° *Leptothorax (Nesomyrmex) sp. 9*	-	1*	1	3	x?		
° *Megalomyrmex balzani*	-	2	2	7,6	x		
° *Pheidole sp. 11*	11	-	11	1,4	x?		
° *Pheidole sp. 15*	-	5	5	1,4	x?		
° *Pheidole sp. 18*	-	13	13	1,1	x?		
° *Pheidole sp. 55*	1	-	1	1,6	x?		
° *Pheidole sp. 68*	-	1*	1	3,2	x?		
Solenopsis (Diplorhoptrum) sp. 8	-	1	1	1,1	x?		
° *Cyphomyrmex dentatus*	-	2	2	1,9	x?		
Subf. Pseudomyrmecinae							
° *Pseudomyrmex elongatus*	1	-	1	3,1	x?		
° *Pseudomyrmex oculatus*	1	-	1	4,1	x?		
Pseudomyrmex pupa	3	-	3	6,5	x		
Subf. Ponerinae							
° *Discothyrea sexarticulata*	-	1*	1	1,3	x?		
° *Hypoponera sp. 33*	-	1*	1	2,8	x?		
Total no. of ants	**422**	**158**	**580**				
Total no. of species	**33**	**28**	**50**		**37**	**2**	**12**
Total no. of genera	**11**	**13**	**17**		**16**	**2**	**2**

° = collected for the first time; x = mean body length (mm); a = arboricolous; t = terricolous; ? = habitat uncertain; * = queen; - = no records

Table 3. Comparison of the ant fauna obtained from two Cupiuba trees (*Goupia glabra*) at Reserva Ducke near Manaus by fogging the canopy between 1991 and 1994. Data based on ant species given in Table 17.1 of Harada & Adis (1997) and in Table 2 of this study. (The insecticide applied was 1% natural pyrethrum, except at the fourth fogging event in August, 1991 during which synthetic pyrethrum Baythroid 0.15% was used; < > = data of the first fog event; see text for details).

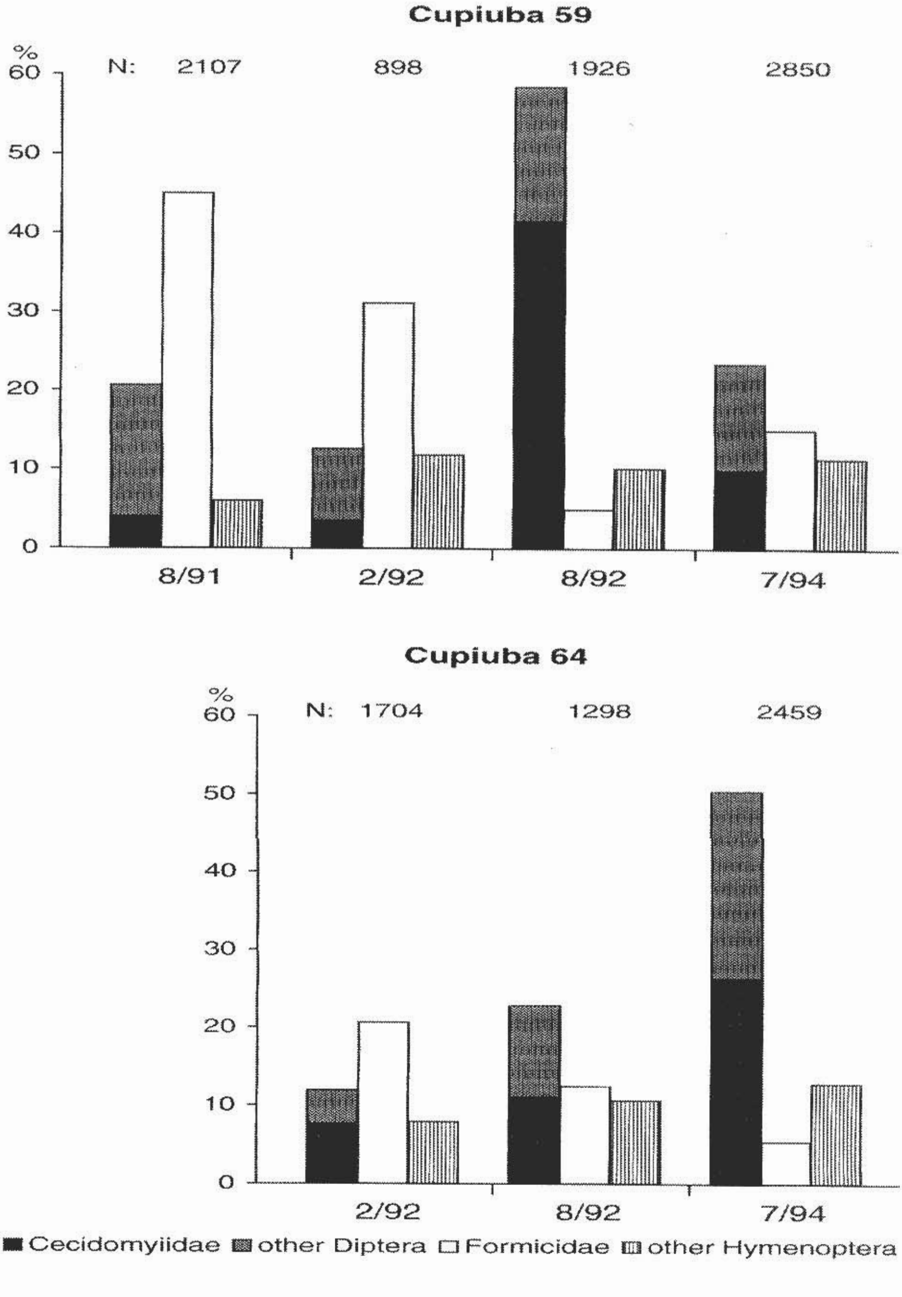
	Cupiuba 59						Cupiuba 64			
FORMICIDAE	8/91		2/92	8/92	7/94	Total	2/92	8/92	7/94	Total
no. of fogging events	4 x	<1x>	1 x	1 x	1 x	7 x	1 x	1 x	1 x	3 x
no. of ants	1718	<905>	334	85	422	2559	328	148	158	634
no. of species	67	<43>	25	20	33	95	33	28	28	59
ratio ants/species	25.6	<21.0>	13.4	4.3	12.8	26.9	9.9	5.3	5.6	10.7
no. of genera	16	<15>	14	11	11	19	12	12	13	19
singletons per species	27 (40.3%)	<11> <(25.6%)>	13 (52.0%)	11 (55.0%)	13 (39.4%)	40 (49.4%)	13 (39.4%)	10 (35.7%)	13 (46.4%)	17 (27.9%)
dubletons per species	8 (11.9%)	<5> <(11.6%)>	3 (12.0%)	6 (30.0%)	3 (8.8%)	11 (13.6%)	4 (12.1%)	6 (21.4%)	3 (10.7%)	10 (16.4%)
abundant species (> 25 ind.)	6 (9.0%)	<6> <(14.9%)>	2 (8.0%)	1 (5.0%)	4 (11.8%)	14 (14.4%)	3 (9.1%)	0 (0.0%)	18 (64.3%)	4 (6.6%)
species turnover	- -	- -	9 (36.0%)	6 (30.0%)	14 (42.4%)	- -	- -	14 (50.0%)	1 (3.6%)	- -
recolonization of species	-	-	0	1	3	-	-	0	2 (7.1%)	-
colonization of additional species	-	-	0	0	2	-	-	0	4-6	-

July, 1994 (Tab. 3). The number of Cecidomyiidae, however, increased (from 119 to 766 specimens; Tab. 1). The opposite was observed in Cupiuba 59: the number of ant specimens and species had increased (from 88 to 422 and from 20 to 33, respectively; Tab. 3) but the amount of Cecidomyiidae had decreased (from 850 to 385 specimens (Tab. 1), results at species level not yet available; cf. Fig. 5: top). Data indicate a biotic interaction between - 1) predating ants (probably *Crematogaster* spp.) and the gall building Cecidomyiidae and - 2) between Cecidomyiidae and the parasitic Hymenoptera. This was not known from previous studies in the tropical canopy. To our knowledge (Adis *et al.*, 1998), there are no field data showing the specific predation of Diptera (eggs, larvae, pupae, "galls") by ants.

Some ecological investigations, however, have led to the assumption that -1) the population density of leaf-mining larvae of Diptera and Lepidoptera is being non-selectively controlled by ants; -2) the exclusion of ants can have a direct effect on the attack of parasitoids if ants interfere with searching by the adult parasitoid. Thus herbivores tended by ants have been shown to suffer less parasitoid attack than untended herbivores (see review in Memmott *et al.,* 1993).

Stork (1988, 1991) obtained a low number of ant species (n=10-32; 3.1% of the total arthropod species) from each of ten Bornean canopies in a lowland floodplain forest, but a high number of species of other Hymenoptera (n=37-267; 23% of the total arthropod species), predominantly parasitic Chalcidoidea (739 species). The families of Nematocera known to parasitise the galls of Cecidomyiidae in Central Amazonian tree canopies (Eulophidae, Eurytomidae, Pteromalidae, Torymidae; Adis *et al.*, 1998) represented 40% (n=298) of the Chalcidoidea species

Figure 5. Percentage of Diptera, Cecidomyiidae, Formicidae and other (mainly parasitic) Hymenoptera of the total number of arthropods (N) obtained by canopy fogging between 1991 and 1994 from two Cupiuba trees (*Goupia glabra*) at Reserva Ducke near Manaus (refogging intervals 6 or 24 months).



and 46% (n=667) of all specimens obtained on Borneo. The Diptera on Borneo amounted to 22% of the arthropod species and specimens collected. The Cecidomyiidae, Ceratopognidae, Chironomidae and Sciaridae represented 91% (n=3362) of the specimens and 69% (n=119) of the species of all the Nematocera obtained. At Manaus (Tab. 1), specimens of these groups amounted to 89% of the total Nematocera. The Cecidomyiidae represented 47 - 62% of the Nematocera specimens collected and at least 13 species (preliminary classification on morphospecies level). On Borneo, 26 species of Cecidomyiidae represented 15% of the total Nematocera specimens.

The data from tree canopies on Borneo suggest that a low number of ant species might result in a reduced predation of Cecidomyiidae galls by ants, which favours an interaction primarily between the parasitic Hymenoptera and the Cecidomyiidae. Field experiments might elucidate the general interactions between Formicidae, Cecidomyiidae and parasitic Hymenoptera in both Neotropical and Southeast Asian canopies of tropical lowland forests. At Manaus and at the Rio Orinoco, twigs of trees with Cecidomyiidae galls could be protected from ant attacks, e.g. by mesh-bags. On Borneo, carton nests of non-competitive ant species could be added to the canopy (Maschwitz, personal communication) and the response of gall building Cecidomyiidae monitored. In both cases, however, results have to be compared on species level.

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Literature cited

Adis, J.; Lubin, Y.D.; Montgomery, G.G. 1984. Arthropods from the canopy of inundated and terra firme forests near Manaus, Brazil, with critical considerations on the pyrethrum-fogging technique. *Studies on Neotropical Fauna and Environment*, 19(4): 223-236.

Adis, J; Paarmann, W; Fonseca, C.R.V. da; Rafael, J.A. 1997. Knockdown efficiency of natural pyrethrum and survival rate of living arthopods obtained by canopy fogging in Central Amazonia. *In:* Stork, N.E.; Adis, J.; Didham, R.K. (eds.) *Canopy arthropods.* Chapman ; Hall, London: 67-81.

Adis, J; Harada, A.Y.; Rafael, J.A.; Vidal, S. 1998. Kontrollieren Ameisen die Dipterenfauna neotropischer Baumkronen? *Verhandlungen Westdeutscher Entomologentag Düsseldorf 1997* (Löbbecke-Museum Düsseldorf): in press.

Erwin, T.L. 1983. Tropical forest canopies: the last biotic frontier. *Bull. Ent. Soc. America,* 29(1): 14-19.

Erwin, T.L. 1989. Canopy arthropod biodiversity: a chronology of sampling techniques and results. *Revista Peruana de Entomologia,* 32: 71-77

Floren, A; Linsenmair, K.E. 1997a. Diversity and recolonization dynamics of selected arthropod groups on different tree species in a lowland rainforest in Sabah, Malaysia with special reference to Formicidae. *In*: Stork, N.E.; Adis, J.; Didham, R.K. (eds). *Canopy arthropods.* Chapman Hall, London: 333-381.

Floren, A; Linsenmair, K.E. 1997b. Diversity and recolonisation dynamics of arthropod communities in a lowland rain forest in Sabah, Malaysia. *In:* Ulrich, H. (ed) *Tropical biodiversity and systematics.* Proceedings of the International Symposium on Biodiversity and Systematics in Tropical Ecosystems., Bonn, 1994. Zoologisches Forschungsinstitut und Museum Alexander Koenig, Bonn: 245-249.

Harada, A.Y.; Adis, J. 1997. The ant fauna of tree canopies in Central Amazonia: a first assessment. *In*: Stork, N.E.; Adis, J.; Didham, R.K. (eds). *Canopy arthropods.* Chapman ; Hall, London: 382-400.

Hero, J.M. 1990. An illustrated key to tadpoles occurring in the Central Amazonian rainforest, Manaus, Amazonas, Brazil. *Amazoniana*, 11(2): 201-262.

Höfer, H.; Brescovit, A.D.; Adis, J.; Paarmann, W. 1994. The spider fauna of Neotropical tree canopies in Central Amazonia: first results. *Studies on Neotropical Fauna and Environment*, 29(1): 23-32.

Linsenmair, K.E. 1990. Tropische Biodiversität: Befunde und offene Probleme. *Verhandlungen der Deutschen Zoologischen Gesellschaft,* 83: 245-261.

Loureiro,A.A.; Silva, M.F. da 1968. *Catálogo das madeiras da Amazônia.* Vol.1, SUDAM, Belém. 433 p.

Memmott, J.; Godfray, H.C.J.; Bolton, B. 1993. Predation and parasitism in a tropical herbivore community. *Ecological Entomology,* 18: 348-352.

Penny, N.D.; Arias, J.R. 1982. *Insects of an Amazon forest.* Columbia University Press, New York. 269 p.

Prance, G.T. 1990. The floristic composition of the forests of central Amazonian Brazil. *In*: Gentry, A.H. (ed). *Four Neotropical Rainforests.* Yale University Press, New Haven: 159-174.

Ribeiro, M. de N.G.; Adis, J. 1984. Local rainfall variability - a potential bias for bioecological studies in the Central Amazon. *Acta Amazonica,* 14(1/2): 159-174.

Seifert, B. 1993. Die freilebenden Ameisen Deutschlands (Hymenoptera: Formicidae) und Angaben zu deren Taxonomie und Verbreitung. *Abhandlungen und Berichte des Naturkundemuseums Görlitz,* 67(3): 1-44.

Stork, N.E. 1988. Insect diversity: facts, fictions and speculations. *Biological Journal of the Linnean Society,* 35: 321-337.

Stork, N.E. 1991. The composition of the arthropod fauna of Bornean lowland rain forest trees. *Journal of Tropical Ecology,* 7: 161-180.

Stork, N.E.; Brendell, M.J.D. 1990. Variation in the insect fauna of Sulawesi trees with season, altitude and forest type. *In*: Knight, W.J.; Holloway, J.D. (eds). *Insects and the rain forest of South East Asia (Wallacea).* Royal Entomological Society of London, London:173-190.

Strümpel, H. 1985. Mutualistische Beziehungen zwischen neotropischen Buckelzirpen (Homoptera: Membracidae) und Ameisen. *Verhandlungen der Deutschen Zoologischen Gesellschaft,* 78: 342.

Willis, E.O. 1977. Lista preliminar das aves da parte noroeste e áreas vizinhas da Reserva Ducke, Amazonas, Brasil. *Revista Brasileira de Biologia*, 37(3): 585-601.

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