AMAZONIANA	X	1	113 – 125	Kiel, Dezember 1986

Experiments on colonization of small water bodies by Culicidae and Chironomidae as a function of decomposing plant substrates and their implications for natural Amazonian ecosystems

by

Ilse Walker

Dr. Ilse Walker, Departamento de Ecologia, Instituto Nacional de Pesquisas da Amazônia (INPA), Caixa Postal 478, 69.000 Manaus – AM, Brasil.

(accepted for publication: December 1986)

Abstract

The effect of submersed organic matter in decomposition on colonization of small water bodies by insects (notably Culicidae and Chironomidae) was analysed. It was found that grass (*Echinochloa polystachea*) is decomposed by bacteria, and that oviposition by Culicidae is correlated to bacterial density. In containers with submerged forest litter (decomposing prevalently by fungi) bacterial densities remain roughly as low as in water controls, and oviposition by Culicidae is sporadic. Green leaves of forest trees show an inconsistent pattern except for the correlation between bacterial density and colonisation by Culicidae. Chironomidae are little affected by the substrate in decomposition during the one month of the test series. Initial water quality (black, rain, pH, conductivity) has little or no effect on decomposition and on colonization processes, and development of the aquatic insects is normal under all regimes provided there is food for the larvae. Water quality, however, is the r e s u l t of the decomposition process: specific pH-values are stabilised by the plant substrates. Decomposition of forest litter by fungi inhibits growth of bacteria. The results are suggestive for possible interrelations between chemical, biological and ecological factors in natural, Amazonian waters (Fig. 3).

Keywords: **Aquatic decomposition, Culicid ecology, Aquatic food webs, Aquatic microbiology.**

0065-6755 / 1986 / 113 / © MPI für Limnologie, AG Tropenökologie, Plön; INPA, Manaus

1. Introduction

Within a wider program on nutrient cycling and trophic structure in amazonian waters (WALKER & FRANKEN 1983; WALKER in press) a number of experiments were set up in order to identify the possible effects of decomposition on the nature of aquatic food webs. This is of particular importance with regard to the two basic, aquatic ecosystems in Central Amazônia: firstly, the sediment-rich, more or less neutral "white water" with its rich flora of macrophytes, particularly gramineae, which line the banks of rivers and lakes and form the floating meadows; and secondly, the nutrient-poor, acid, clear or black forest waters, essentially devoid of macrophytes but with submerged, decomposing forest litter (SIOLI 1984). Rates of growth and decomposition of the macrophytes in white water and the ecological function of herbivory were investigated by JUNK & HOWARD-WILLIAMS (1984). Information on the food chains depending on the decomposition of the naturally dying fraction of macrophytes is, however, still lacking. In acid clear and black waters (forest streams and rivers, inundation forest of the Rio Negro) food chains start essentially with submerged litter and its decomposing fungi (FITTKAU 1967; IRMLER 1975; SIOLI 1975; WALKER 1985; KENSLEY & WALKER 1982). A striking phenomenon that parallels these ecological differences is the abundance of molesting, blood-sucking aquatic insects in white-water regions and their relative scarcity in black-water regions. This contrast was emphasized by VON HUMBOLDT as early as 1859, and JANZEN (1974) attributed the apparent paucity of aquatic invertebrates in black waters to toxic, phenolic substances released by the decomposing litter, the assumption thus being, that the composition of the invertebrate fauna is a d i r e c t function of the chemical properties of the water. Other authors follow a similar line of thought (ANONYMOUS 1967). Some casual observations, however, suggest that the sequence of cause and effect may be more complicated: containers of standing water with dead plant matter turn usually turbid and putrid by bacterial activity within a period of days, whereas the water of aquaria stocked with dead forest leaves turns acid and remains clear and odour-less (personal observations). Thus, the process of decomposition may condition the water, and the aquatic, invertebrate fauna may be determined by either the plant substrate, or the decomposing micro-organisms, by water chemistry or by any combination of these factors.

By a series of tests I tried to isolate the effects of vegetation in decomposition on the pattern of colonization from the direct effects of natural water quality. The results turned out to be surprizingly consistent and are undoubtedly of relevance for the general ecology of Amazonian aquatic systems.

2. Material and Methods

The following p l a n t s u b s t r a t e s were used for the c o l o n i z a t i o n tests: 1. The Graminea *Echinochloa polystachea*, a natural component of the floating meadows in white water regions – yet collected in the region of the black river Tarumã Mirím (ca 30 km NE of Manaus) where it had been introduced in an unsuccessful attempt to breed cattle. 2. Ten species of undamaged, dried forest leaves from the natural litter in the black-water inundation forest (= igapó) of the river Tarumã Mirím; they were collected before the water inundated the forest. 3. Undamaged, fresh, green

leaves from 14 species of trees of the same area. The species include members of the families Melastomataceae, Leguminosae, Rubiaceae, Lecididaceae, Apocynaceae, Myrtaceae, among others.

Water: 1. Rain water collected from a two year old, painted brasilit (~ eternit) roof in Manaus, collected a few min after the start of heavy rains; 2. Black water from a small stream draining sandy soil in the Tarumã Mirím region. The values of pH and of conductivity are given in the tables with the results.

Containers: Commercial plastic buckets of red colour, 8 liter volume.

Methods: From March to June 1985 three series of monthly tests were run in order to compare insect colonization in containers with the various plant substrates submerged under either black or rain water. The number of replicates in the three test series under the various plant/water regimes are indicated in Table 1. Plant matter ranged from 8 - 18 g (dry weight) per bucket, grass being at the lower edge of this range. Water volume was 3 l in series I, and 2 l in series II and III. The grass was cut into pieces of ca 15 cm, and in the third test the green and dry leaves were cut into 3 - 4 pieces in order to intensify the growth of microorganisms. In all containers the water surface was broken by plant pieces which either touched, or pierced through, the surface film of the water, thus, there was ample support for insects to settle for oviposition. The containers were placed in two rows of alternating regimes on a roofed, open terrace. No measures were taken to protect the air space above the containers from the normal activity of birds and bats. Before introduction into the containers, grass and leaves were washed separately in rain water. This washing water was then mixed and stirred, and 50 ml were given into each container in order to avoid extreme bias of the natural microbial and fungal contamination. When the first culicid larvae pupated, (~ 12. day), all insect larvae of the test series were filtered off through a silk cloth and preserved in alcohol. In test I, the plant matter was set up again in new rain water; the oviposition tests were then resumed for a second period. In test III the plant substrate was re-introduced into its own filtered water after the extraction of the insect larvae; no second period was run for grasses in test II. After the second period (a total of 30 - 32 days including the 1. period) all insect larvae were removed again and stored for counting.

Electric conductivity and pH were measured in both periods. Bacteria and bacteriophagous flagellates were counted in a Thomas chamber at 600x magnification (2 samples of 16 squares of 0.0025 mm^2). Insect counts of over 1000 per replicate include an error of ± 10 % because sub-samples only were counted in these cases. There was also some loss in the filtration process because larvae tended to hold on to the plant material despite vigorous shaking, this specifically on the hirsute grass. Culicid egg masses were counted every morning. Chironomid egg masses were recorded when visible, but, as they were often hidden, they could not be counted systematically.

Bacteriocidal tests. In order to find out whether submerged leaf litter and/or its fungal flora had an inhibitory effect on bacterial growth, snake skin, newly shed and naturally infected with bacteria and fungus spores (as verified under the microscope) was incubated with cut-up forest litter in deionized water. Snake skin (of a young *Boa constrictor*, personal pet animal of the author) was used because of its film-like characteristics and its transparency: the natural growth of fungi and bacteria can be displayed directly under the microscope. Cups of 150 ml volume were provided with 75 ml water and a same mixture of leaf bits from 10 different litter leaves. These leaves were collected in the igapó forest before inundation and had then been submerged in the Rio Tarumã Mirím for one month. Hence, it was assumed that fungal activity was well developed. Six experimental cups received 3 pieces (ca 1 cm^2) of snake skin. Controls (6 cups) contained snake skin pieces and water only. To avoid initial bias of infection, all skin pieces were kept for one hour in a common cup (150 ml) with deionized water.

3. Results and immediate conclusions

3.1. Qualitative observations

In cultures with g r a s s the water turned turbid and aquired a foul smell owing to high bacterial densities after 2 - 3 days, moreover, a thick surface film developed. This state

continued for 6 - 8 days, and in this period intense oviposition by various culicids took place. Later, the filterfeeding larvae, feeding on the bacteria, penetrated and reduced the surface film and eventually cleared the water again, restoring its transparency. The offensive smell disappeared as well. This process was similar in rain and black water except for a one-day delay in oviposition by the culicids in black water. During and after the clearing period oviposition by the culicids was much reduced and remained low after the larvae had been filtered off. During the second period the partly decomposed grass did not develope renewed, high bacterial densities, neither in fresh rain water nor if reintroduced into its old culture water (test III). The grass tissues were evidently dead and discoloured after ca 8 days, and after one month were partly shredded into small bits.

In cultures with g r e e n l e a v e s the water turned slightly turbid within the first 12 days in tests I and II, but not in test III, in which the leaves were cut into pieces. In all three series ca 70 % of the tissues looked still fresh and green after one month, but all cultures developed a gelatinous, transparent surface layer.

Cultures with d r y l i t t e r l e a v e s developed a thin, partly iridescent surface film towards the end of the test month; the water remained essentially clear and odourless throughout. All containers collected numerous dead insects on their surface in the course of the test month.

3.2. Insects colonizing the cultures

The following insect types were found to colonize the containers:

a) Four species of Culicidae, one of which appeared only twice;

b) At least two species of Chironominae (= Tendipedinae) and one species of predatory chironomid (Pelopiinae = Tanypodinae). All three culicid and chironomid species appeared on all substrates and in both kinds of water; they are therefore not itemized in the Tables and Figures.

c) One type (probably a single species) of muscid larva;

d) Some larvae of Psychodidae appeared in most containers, they are not listed in the Tables and Figures;

e) Occasional adult notonectids (Hemiptera) and small beetles (Elmidae), which are not mentioned in the Tables and Figures.

3.3. Quantitative results of colonization tests

Table 1 summarizes the quantitative results. As the results of tests I and II were reasonably similar, they were combined into the same mean.

Obviously, neither overall bacterial density, nor flagellates nor any of the insect groups reacted specifically to black water; differences between series (I + II $\gtrless$ III) w i t h i n water types are larger than b e t w e e n water types (black $\gtrless$ rain) for grass and green leaves (dry litter leaves have too few replicates in black water to make statements). Grass developed vastly higher bacterial densities and μS_{20}-values than the other substrates ($P < 0.01$ in all cases, t-test), and the flagellates, which were actually observed to ingest bacteria, were detectable only if bacterial densities exceeded $8 \cdot 10^6$/ml.

Tab. 1: Colonization of experimental containers with various plant materials in rain and black water by the following organisms (mean number per container, n = number of containers): Bacteria (B), bacterivorous flagellates (F), Culicid egg masses (CuE), Culicid larvae (Cu), Chironomidae (Ch), muscid larvae (M). Means of Tests I and II combined. The values of conductivity and of bacterial density refer to first test period (see p. 115).

MATERIAL	GRASS		GRENN LEAVES		DRY LEAVES		WATER ONLY	
H_2O Initial Conditions	B, F (10^6/ml) μS_{20}/cm n	Insect Larvae	B, F (10^6/ml) μS_{20}/cm n	Insect Larvae	B, F (10^6/ml) μS_{20}/cm n	Insect Larvae	B, F (10^6/ml) μS_{20}/cm n	Insect Larvae
RAIN H_2O	B 216.17	CuE 34	B 18.00	CuE 19.5	B 8.33	CuE 1.8	B 2.87	CuE 1.5
I II	F 7.80	Cu 2188	F 2.50	Cu 377	F (0)	Cu 75	F (0)	Cu 7.5
pH 6.1 6.9	167.3 ± 33.5	Ch 833	56.7 ± 17.6	Ch 419	31.4 ± 13.4	Ch 509	16.5 ± 2.7	Ch 515
µS12.0 18.7	n = 6	M 128	n = 4	M 17	n = 6	M 2	n = 4	M 1
III	B 47.0	CuE 43	B 2.25	CuE 0	B 0.03	CuE 0		
	F 5.1	Cu 1098	F (0)	Cu 0	F (0)	Cu 0		
pH 4.8	103.2 ± 2.6	Ch 648	46.1 ± 4.6	Ch 299	11.7	Ch 47		
µS 5.3	n = 2	M 194	n = 2	M 0	n = 1	M 0		
BLACK H_2O			B 17.5	CuE 18.5	B –	CuE 1		
II			F 11.0	Cu 825	F –	Cu 0		
pH 3.5			52.0 ± 3.1	Ch 746	µS –	Ch –		
µS27.0			n = 2		n = 1			
III	B 37.25	CuE 41	B 4.0	CuE 1.5	B (0)	CuE 0		
pH 3.6	F 1.63	Cu 1852	F (0)	Cu 5	F (0)	Cu 0		
µS17.1	85.9 ± 9.9	Ch 674	13.4 ± 5.2	Ch 118	12.5	Ch 387		
	n = 4	M 239	n = 2	M 0	n = 1	M 0		

There is unmistakable correlation between bacterial density and the number of culicid egg masses on the one hand ($r = 0.58$; $P < 0.05$) and between bacterial density and conductivity on the other ($r = 0.90$). This suggests that mature mosquito females are attracted by bacteria-rich waters, and that high bacterial activity releases a flush of ions from the decomposing grass; in addition there is the metabolism of the filter-feeding culicid larvae. It appears that the grass releases its nutrients during the first period only: in test I the grass was re-introduced into fresh rain water after filtering off the larvae on day 14; the conductivity of this fresh water was then 13.3, yet on day 31, when the test ended, it had risen to only 18.0 (not shown in Table 1). This correlates again with the observation that the water in all grass cultures remained clear in the second test period, despite the fact that all filter-feeding larvae had been removed. In other words, the transparency of the water in the second period is due to primary absence of bacterial activity and not to removal of bacteria by filter-feeding.

There is no correlation between number of chironomids and bacterial density and/or conductivity. Chironomids are scraping leaf surfaces and shredding plant tissues and other debris, for instance dead insects, which they hollowed out and used as tubes instead of building their own, in the water controls.

All types of insects developed normally on all types of plant material and in black and clear water. However, in the case of excessively low bacterial densitites culicid development was retarded and some larvae eventually died (for instance test III, green leaves: 21 days after oviposition the larvae had not pupated yet, whereas larvae of the same age on the grass cultures pupated on the 11^{th} day). We thus conclude that neither fresh, green forest leaves, nor leaves of forest litter, have a toxic effect on the aquatic insect fauna, but that filter-feeding larvae may die of starvation due to excessively low density of food particles in presence of these plant substrates.

No definite reason can be given for the different results on green leaves between test II and III. In test III, though, the leaves were cut into pieces; this may have led to a release of antibacterial substances by the tissues thus wounded.

Decomposition of the grass falls into two distinct phases. This is shown in Table 2. The first period is characterized by high bacterial densitities, by intense culicid oviposition and development, and the pH is solidly buffered between 5.1 and 5.4. This period enriches a planctonic, filter-feeding community. In the second period bacterial growth and culicid oviposition are reduced and the chironomids take over; the pH is buffered at 6.6 - 6.7. This is a benthic phase of decomposition. Table 2 confirms, moreover, that initial water quality has no effect on these decomposition processes. The process of decomposition is not primarily a function of water quality, but water quality is a function of the decomposition process.

Tab. 2: Culicid-Chironomid-succession (first and second period) on the decomposing grass *Echinochloa polystachea* in rain and in black water.
$\bar{x} \pm s$ = mean values per container and standard deviation;
n = number of containers.

Parameter	H_2O	First Period ~ 1 - 10 day $\bar{x} \pm s$	n	Second Period ~ 11 - 30 day $\bar{x} \pm s$	n	$P \leqslant$
	Rain	5.40 ± 0.12	8	6.71 ± 0.35	6	0.001
pH	Black	5.07 ± 0.11	4	6.63 ± 0.15	4	0.001
	$P \geqslant$	0.45		0.45		t - Test
Bacteria	Rain	47.00 ± 10.00	2	13.25 ± 2.75	2	0.05
$\cdot 10^6$/ml	Black	37.25 ± 8.40	4	16.37 ± 7.76	4	0.0125
	$P \geqslant$	0.25		0.25		t - Test
Culicid	Rain	32.80 ± 9.80	8	6.3 ± 3.0	6	0.01
egg	Black	33.30 ± 10.70	4	7.5 ± 2.5	4	0.01
masses	$P \geqslant$	0.49		0.49		χ^2-Test
Culicid	Rain	1320 ± 511	6	115 ± 78	6	0.005
larvae	Black	1591 ± 404	4	135 ± 54	4	0.025
	$P \geqslant$	0.10		0.10		Wilcoxon Test
Chiro-	Rain	27 ± 44	6	747 ± 200	6	0.005
nomid	Black	65 ± 85	4	608 ± 258	4	0.025
larvae	$P \geqslant$	0.10		0.10		Wilcoxon Test.

The overriding buffer effect of the plant substrate in decomposition is shown in Fig. 1. Decomposition of litter by fungi stabilizes acid pH values; decomposition of grass near neutral values; the acid phase was short-lived and was probably due to a synchronous release of organic acids, which were then broken down further. The scattered values of dry leaves in test I on day 15 may be due to bird or bat droppings that fell into the buckets. However, on day 31 the values were again solidly acid. As the tissues of green leaves were still mostly alive after one month, and further, as green forest leaves constitute an insignificant fraction of decomposing plant material in natural ecosystems, we dismiss green leaves from further consideration.

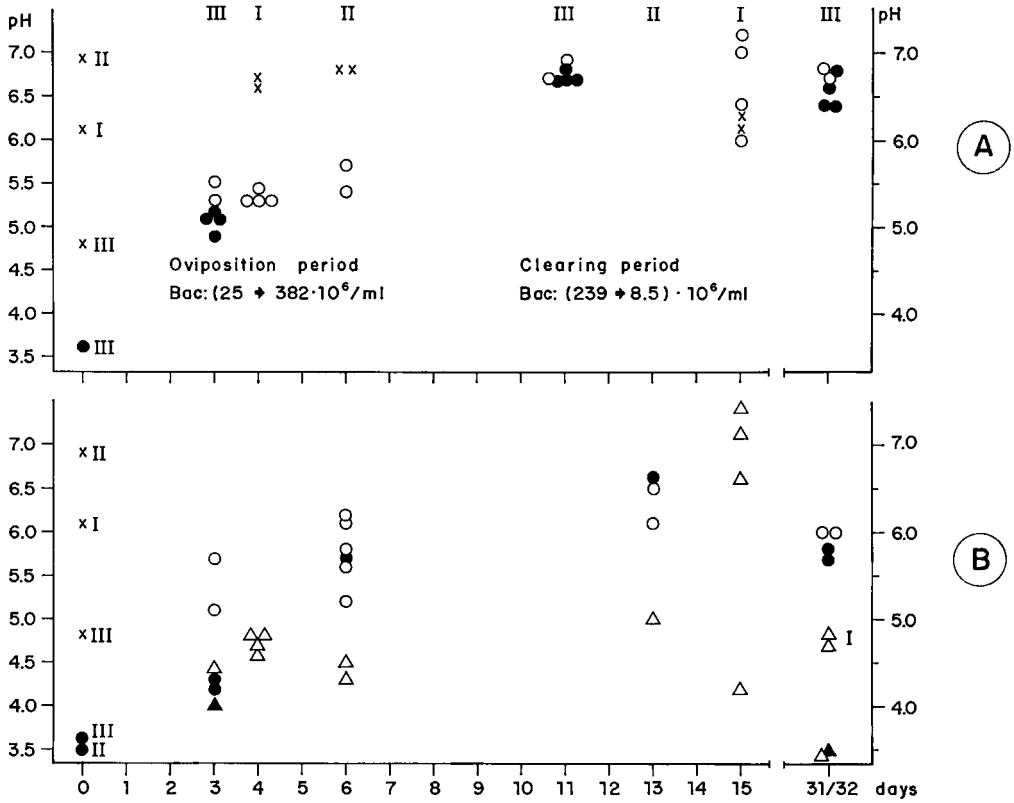

Fig. 1:
pH values in the course of time (days) in the three tests I, II and III. Day zero: initial values of water without substrate. **A:** decomposing substrate = *Echinochloa polystachea*; in black water (black circles); in rain water (open circles). Crosses: controls without grass. Oviposition and Clearing periods are sub-periods of the "First period" in Table 2 and refer to culicid larvae that clear the water of bacteria; Bac = range of bacterial densities during sub-period.
B: substrate = fresh, green forest leaves (circles) and dry litter leaves (triangles). Black symbols: black water; open symbols: rain water.

3.4. Growth inhibition of bacteria by fungi

Repeated examination of snake skin from the controls (water only) during the first two hours after submergence showed rapid growth of bacteria. After 24 h the density of bacteria on the keratin scales was ca 10/25 μ^2 and on the 3rd day above 100/25 μ^2, i. e. the skin piece was uniformely covered by, and swarming with, bacteria; (exact counting on the skin was not possible because the depth of the preparation did not allow for exact focusing). The density of the bacteria suspended in the water was roughly stationary from the 2nd to the 9th day in the controls and experimentals; the means of 4 counts each on the 2nd, 3rd and 9th day were (7.5 - 10.5) 10^6/ml in the controls and (2.5 - 4.5) 10^6/ml for the experimentals incubated with leaf litter. The difference is significant in the χ^2-test ($P < 0.05$), but owing to large variance, not in the t-test ($0.05 < P < 0.10$). More interesting, though, was the appearence of the e x p e r i m e n t a l skin pieces. On the third day

they were grown over by a dense web of fungus hyphae of one or several species, and sporulation was just beginning (Fig. 2a, b: six pieces examined). Thinly spread, and in places clumped, bacteria of various types were also present. On the 9th day sporulation was fully developed or in the end phase already; zoospores were much in evidence and were beeing ingested by vorticellids (Ciliata). The pattern of bacterial occupation was similar to the one on the 3rd day. Of the six c o n t r o l s examined on the 9th day two pieces contained few isolated and limited fungus colonies (3 species) which, however, showed no sporangia. Small, bacteria-feeding ciliates (*Tetrahymena* ?) were dense on all control pieces (~ 10/mm^2) and sporadic only on the experimentals.

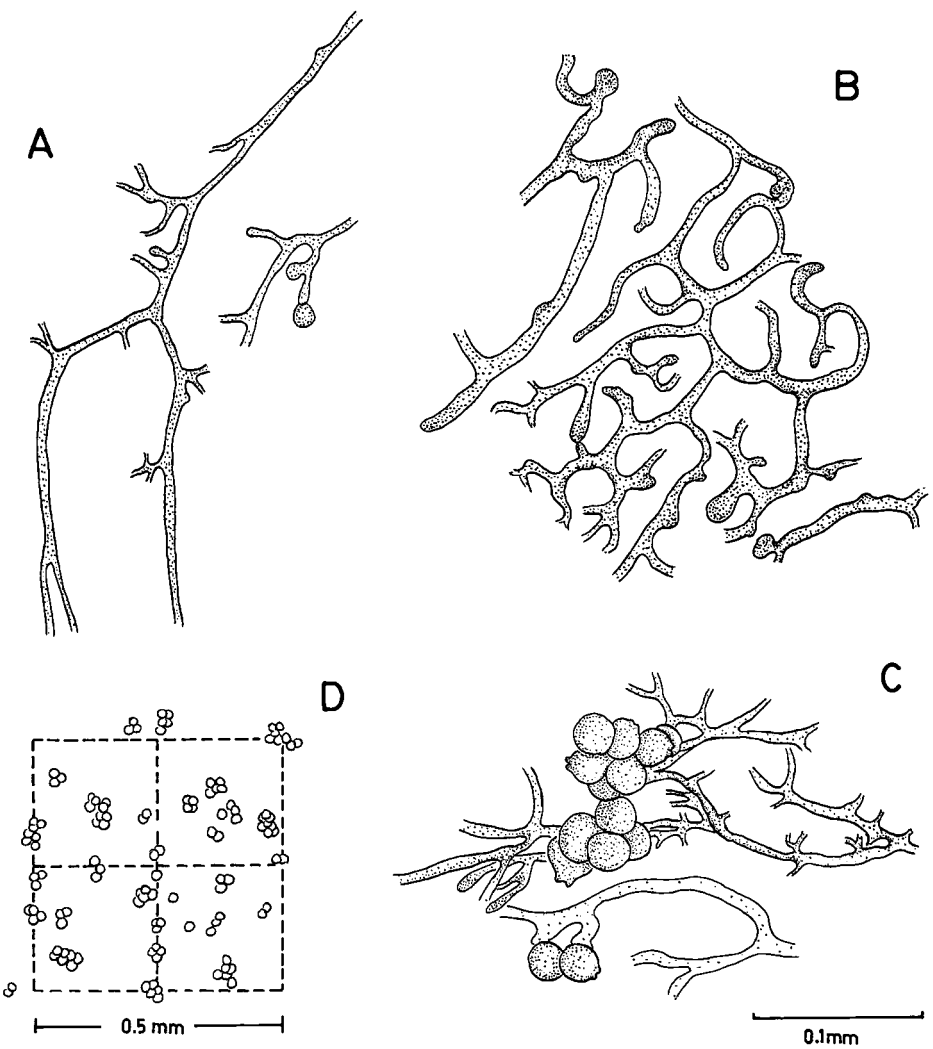

Fig. 2:
A, B, C: various fungi colonizing experimental samples of snake skin. **D:** overall density of the sporangia of the fungus in C. Camera lucida drawings.

Thus, qualitative, comparative examination of the skin pieces leaves no doubt that the presence of litter decomposing fungi promotes decomposition of foreign (animal) substrates by fungi and further, that fungus mycelia strongly inhibit the growth of those bacteria that would otherwise dominate the decomposition of the substrate. Lower density of suspended bacteria does not necessarily mean that the fungi release anti-bacterial substances into the water, it may merely reflect the lower number of bacteria on the skin pieces. However, the short, but neat, delay of oviposition by culicids on grass in black water may point to bacteria-inhibiting substances in black water, in that mature mosquito females were less attracted by initially lower bacterial densities: in test III the mean number of culicid egg masses per container in black water on the days 1, 2, 3, were 0.25, 2.0 and 19.75; in rain water, however 4.0, 7.5 and 19.0 respectively ($P < 0.05$ on days 1 and 2; χ^2-tests). The results of this preliminary microbiological test clearly call for elaboration of critical, quantitative methods by experts in the systematics of fungi and bacteria. Keratin scales of naturally shed snake skin may be a useful substrate to study certain classes of aquatic fungi.

4. General Conclusions

Fig. 3. summarizes the sequence of causes and effects as it appeared from the experimental series, and relates it to the pattern of large-scale ecology, as it emerged from the field studies of the last decades (SIOLI 1984): the igapó of the Rio Negro system with its affluent forest streams and rivers on the one hand, and the Solimões/Amazonas with the white and mixed water várzea lakes on the other.

The central fact clearly demonstrated in the experiments is that the type of submerged plant substrate determines the microbiological pattern of its own decomposition, and that colonization by organisms on higher trophic levels is first and foremost a function of the plant substrate in decomposition, and not of primary water quality. The reaction of pH and of conductivity in the experiments imply that large scale decomposition processes must have marked effects on natural water quality.

Beside the remarkable coincidence of natural and experimental pH-ranges in Fig. 3, and of presence and absence of molesting mosquitoes, the interrelations in the diagram are substantiated by the following, specifically pertinent observations. 1. JUNK & HOWARD-WILLIAMS (1984) state that the graminea that are common in the várzea, are apparently not able to colonize poor, acid waters; that their tissues are low in cell wall content and that *Polystachea*, for example, looses 50 % of dry weight within 15 days of decomposition, whereas litter leaves with high cell wall contents take months to decompose. 2. Total average density of bacteria in the Rio Negro (FONSECA et al. 1982) and in the mouthbay lake of the black river Tarumã-Mirím is 500 to several thousand times lower than in várzea lakes (RAI & HILL 1980), and seasonal changes of bacterial densities in the várzea are correlated with the periodicity of growth and decomposition of the periphyton (RAI & HILL 1984). 3. The mean conductivity of four headwater streams of the rio Tarumã-Mirím was 14.75 ± 2.90 μS_{20} (range = 11.9 - 16.4; WALKER, in preparation), whereas one year's data from the river's mouthbay fluctuated between 6 - 8 μS_{20} IRMLER

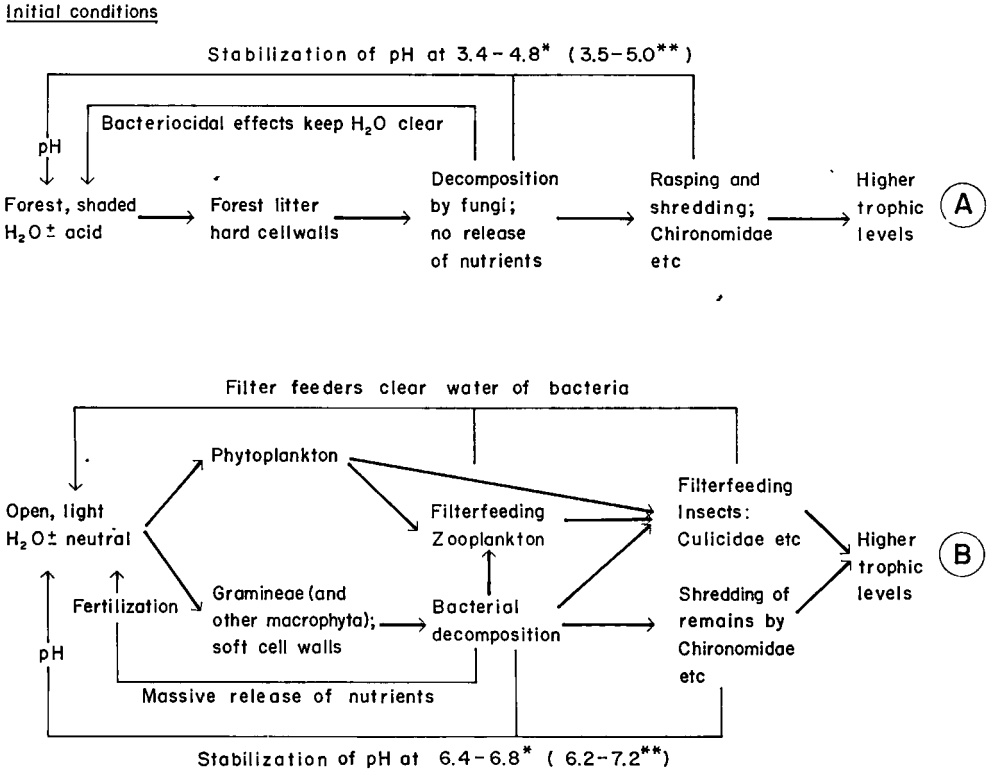

Fig. 3:
Probable interrelations between various ecological factors in black and clear water systems (A; Rio Negro, igapó, forest streams) and in white water systems (B; Solimões, Amazonas, várzea).
* Range of experimental values in Fig. 1; ** Range of values from field studies in black and white water systems (SIOLI 1984).

1975). This indicates that under-water decomposition of forest litter by fungi is retaining, rather than releasing, nutrients into the water. This is plausible because the fungi penetrate into the mesophyll of the leaves before the thick-walled epidermis is broken up. The nutrients are consumed ad hoc and never leach into the water; a depletion effect would also be expected by the activity of the root systems in the igapó and by microorganisms that dwell on the surface of submerged litter leaves. 4. The invertebrate fauna and its food web in the igapó and in forest rivers is predominantly associated with submerged litter and its decomposing fungi (WALKER 1985; WALKER & FERREIRA 1985; KENSLEY & WALKER 1982; NESSIMIAN 1985). The mean number of chironomids colonizing single, submerged leaves within 2 - 5 weeks in the Tarumã-Mirĩm is 9.9; the number on randomly collected leaves in forest streams is 18.3 (WALKER in preparation), and dead, discoloured grass blades from a várzea lake are as intensely colonized by chironomids as are litter leaves in the igapó (Course work, INPA 1985). 5. A snake skin recovered from a small, acid forest stream in 1977 was heavily infected by fungi and almost devoid of bacteria, and it had no offensive smell. During two weeks of incubation in acid stream water (not sterilized), the fungi continued to spread and the bacteria receded further, the accompa-

nying, bacteria-feeding micro-fauna was very poorely developed. Competitive interaction between fungi and bacteria on fish baits exposed in an acid, Amazonian forest stream, and its immediate effect on the accompanying micro-fauna, were also noted by WALKER (1985).

The feed-back loops that drive the systems ever more into a definite direction, are undoubtedly of ecological importance. The fungi reduce bacterial growth and thus facilitate further infection by fungi; litter colonized by fungi stabilizes acid pH-values, and this may optimize fungal growth, as shown for hyphomycetes of soft waters by ROSSET & BÄR-LOCHER (1985). By contrast, decomposition of graminea in white water regions contributes to the buffer of the pH near the neutral point. This favours the growth of graminea and fertilizes their soil and water.

And lastly: the mosquitoe females behave like any other arthropod that has been investigated in this respect: they oviposit where there is food for their offspring, that is, for their filterfeeding larvae that dwell mostly near the water surface.

5. Resumo

Experimentos sobre a écologia aquàtica em função dos processos de decomposição sub-aquàticos

Tres séries (I, II, III) de experimentos em pequenos recipientes (com 2 - 3 lit. de àgua) foram efetuadas a fim de estabelecer o efeito de plantas submersas em decomposição sobre a colonização da àgua por insetos (especialmente Culicidae e Chironomidae). Os resultados mostraram o seguinte (Tab. 1 e 2):

Recipientes com capím (*Echinochloa polystachea*) desenvolvem altos valores de condutividade elétrica e altas densidades de bactéria, e a colonização por Culicidae é intensa durante a primeira fase (dia 1 - 10) do experimento; durante a segunda fase (dia 11 - 30), Chironomidae são mais frequentes.

Em recipientes com serrapilheira (liteira, folhiço) de floresta primària (igapó) e em recipientes de controle com apenas àgua de chuva, condutividade e densidade de bactéria permanecem baixas; oviposição de Culicidae é esporàdica, mas colonização por Chironomidae é da mesma ordem de intensidade. Folhas verdes de àrvores de igapó mostram um padrão de colonização intermediária e inconsistente.

Em geral densidade de bactéria é correlacionada com a condutividade elétrica ($r = 0.900$), e oviposição de Culicidae com densidade de bactéria ($r = 0.58$; $P < 0.05$). Os processos de colonização e de decomposição são os mesmos em àgua de chuva (= rain, Tab. 1, 2) e em àgua preta de riacho de floresta (= black); estes processos são independentes da quîmica inicial destas àguas naturais (pH, condutividade, presença de substâncias orgânicas em solução).

A matéria orgânica em decomposição é um tampão potente para o pH do corpo d'àgua: em recipientes com capím o pH estabiliza nos valores de 6.4 - 6.8, e nos de folhiço nos valores de 3.4 - 4.8 (Fig. 1). Em presença de folhiço submerso, materiais protéicas, que são normalmente decompostas por bactéria (escamas de queratina de cobra), são decompostas por fungos; o crecimento de bactéria està sendo altamente inibido (Fig. 2).

Os resultados, juntos com informções da literatura pertinente, conduzem as interrelações hipotéticas dos fatores quîmicos, biológicos e ecológicos mostrados nà figura 3.

6. Acknowledgments

I am thanking Dr. W. J. Junk and Dr. W. Franken for the permission to use the facilities of their hydrological laboratories.

7. References

ANONYMOUS (1967): River of insecticide.- Time Mag. Aug. 25.: 42.

FITTKAU, E. J. (1967): On the ecology of Amazonian rain forest streams.- Atas do Simpósio sobre a Biota Amazônica, Rio de Janeiro, (Limnologia) **3**: 97 - 108.

FONSECA, O. J. M., SALEM, J. I. & V. L. GUARIM (1982): Poluição e autopurificação do Rio Negro nas cercanias de Manaus.- Acta Amazônica **12**: 271 - 278.

HUMBOLDT, A., VON (1859), new ed. (1958): Vom Orinoco zum Amazonas.- F. A. Brackhans, Wiesbaden: 420 pp.

IRMLER, U. (1975): Ecological studies of the aquatic soil invertebrates in three inundation forests of Central Amazônia.- Amazoniana **5**: 339 - 406.

JANZEN, D. H. (1974): Tropical black water rivers; animals and mast fruiting by the Dipterocarpaceae.- Biotropica **6**: 69 - 103.

JUNK, W. J. & C. HOWARD-WILLIAMS (1984): Ecology of aquatic macrophytes in Amazônia.- In: The Amazon, H. SIOLI (ed.). Dr. W. Junk Publ., Dordrecht: 673 pp.

KENSLEY, B. & I. WALKER (1982): Palaemon shrimps from the Amazon Basin, Brasil (Crustacea, Decapoda, Natantia).- Smithsonian Contributions to Zoology **362**: 1 - 28.

NESSIMIAN, J. L. (1985): Estudo sobre a biologia e a ecologia da fauna invertebrada na liteira submersa das margens de dois lagos do Arquipélago de Anavilhanas (Rio Negro, Amazonas, Brasil).- Tese de Mestrado, INPA/FUA: 120 pp.

RAI, H. & G. HILL (1980): Classification of Central Amazon lakes on the basis of their microbiological and physico-chemical characteristics.- Hydrobiologia **72**: 85 - 99.

RAI, H. & G. HILL (1984): Microbiology of Amazonian waters.- In: The Amazon. H. SIOLI (ed.) Dr. W. Junk Publ., Dordrecht: 673 pp.

ROSSET, J. & F. BÄRLOCHER (1985): Aquatic hyphomycetes: influence of pH, Ca^{2+} and HCO_3^- on growth in vitro.- Trans. Br. Mycol. Soc. **84**: 137 - 145.

SIOLI, H. (1975): Tropical rivers: the Amazon.- In: River Ecology. B. A. WHITTON (ed.). Univ. of California Press, Berkeley and Los Angeles: 725 pp.

SIOLI, H. (ed.) (1984): The Amazon.- Dr. W. Junk Publ., Dordrecht: 763 pp.

WALKER, I. (1985): On the structure and ecology of the micro-fauna in the Central Amazonian forest stream "Igarapé da Cachoeira".- Hydrobiologia **122**: 137 - 152.

WALKER, I.: The biology of streams as part of Amazonian forest ecology.- Experientia: in press.

WALKER, I. & M. J. N. FERREIRA (1985): On the population dynamics and ecology of the shrimp species (Crustacea, Decapoda, Natantia) in the Central Amazonian river "Tarumã-Mirím".- Oecologia **66**: 264 - 270.

WALKER, I. & W. FRANKEN (1983): Ecosistemas frágeis: a floresta da Terra Firme da Amazônia Central.- Ciência Interamericana **23**: 9 - 21.