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Environmental factors influencing the community structure of shrimps and crabs (Crustacea: Decapoda) in headwater streams of the Rio Jaú, Central Amazon, Brazil

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Abstract. Longitudinal variations in physical-chemical characteristics of headwaters streams can have predictable effects on habitat and benthic community structure. The objective of this study was to investigate the influence of spatial variation in river channel characteristics and habitat structure on the abundance and community structure of shrimps and crabs in headwaters streams of Rio Jaú. Collections and measurements for the characterization of crustacean community structure, habitat structure and channel characteristics were made in 34 headwater streams during the period of November - December of 1998. Crustaceans were captured with traps and hand nets along standard two meander sample reaches. Data on benthic habitat structure and stream morphology were collected along ten equally spaced lateral transects. A total of nine species from three families were collected. Significant relationships were obtained between % sand and % leaf cover on stream bottoms and the number and biomass of shrimps and crabs, independent of stream size. Channel size explained a significant part of the variability in decapods community structure among streams. When streams are degraded and habitats are lost, many species restricted to those habitats may disappear and the trophic structure of crustacean communities could change.

Keywords: Amazon, Decapods, benthic community structure, habitats, Jaú , Forest stream.

Resumo: Fatores ambientais influenciando a estrutura de comunidades de camarões e caranguejos (Crustacea: Decapoda) em igarapés de cabeceira no Rio Jaú, Amazônia Central, Brasil. Mudanças longitudinais nas características físicas e químicas de igarapés de cabeceira podem ter efeitos previsíveis na estrutura dos habitats e das comunidades bentônicos. O objetivo desse estudo foi de investigar a influência da variação nos características físico-químicas do canal e estrutura de habitas sobre os camarões e caranguejos em igarapés de cabeceira da bacia do rio Jaú. Coletas e medidas para caracterizar a estrutura da comunidade de crustáceos, estrutura dos habitats e características do canal foram feitas em 34 igarapés de cabeceira durante os meses de novembro e dezembro de 1998. As capturas foram realizadas com covos e rapiché ao longo de dois meandros completos por igarapé. Informações sobre os habitats de fundo e as características físicas do canal foram obtidas ao longo de dez transectos. Um total de nove espécies de crustáceos de três famílias foram coletadas. Foram encontradas relações significativas entre os habitats de fundo de areia e de folha e a abundância (número de indivíduos e biomassa) de crustáceos decápodes. Mudanças no tamanho do rio também explicaram a variação na estrutura dessas comunidades entre igarapés de cabeceira. Quando igarapés são degradados e os habitats alterados, muitas espécies restritas a determinados locais poderiam desaparecer e a estrutura trófica da comunidade poderia ser alterada.

Palavras-chave: Amazônia, Decápode, Estrutura de comunidades bentônicas, habitats, Jaú, igarapé de floresta.

Introduction

The River Continuum Concept (RCC) describes how longitudinal variations in the physical characteristics of streams in forested basins can influence the community structure of benthic invertebrates (Vannote *et al.* 1980, Cargnin-Ferreira & Forsberg 2000), and fishes (Magalhães *et al.* 2002, Poully *et al.* 2005, Romanuck *et al.* 2006) along a fluvial system. While the RCC does not make predictions about the carcinofauna, it is probable that systematic variations in physical-chemical characteristics and habitats structure along the stream size continuum also influence the structure of shrimp and crab communities. Variation in channel width is a key factor in the RCC that influences the availability of light and the distributions of submerged branches, trunks and litter that, in turn, influence the abundance and community structure of aquatic plants and animals along the fluvial continuum (Cummins 1974, Conners & Naiman 1984, Walker 1987). Riparian forests have a strong influence on stream environments, supplying organic energy in the form of leaf litter that is essential for maintaining water quality, secondary production and species diversity (Walker 1985, 1990). The smaller the stream, the more dependent the biota is on leaf litter habitats and allocthonous energy derived directly or indirectly from the marginal forest (Minshall *et al.* 1983, Walker *et al*. 1991).

Information on general aspects of the ecology and reproductive biology of some shrimp species from black water environments of the Rio Negro Basin can be found in the regional literature. Kensley & Walker (1982), in addition to describing new species from this area, also gave valuable information on the habitat preferences and feeding habits of six species from forest streams of the lower Rio Negro. These species were assigned to two ecological groups: 1) species that live and forage inside accumulations of leaf litter and are never observed outside this cover and 2) species that can be observed in open water on sandy bottoms and occasionally take refuge in leaf litter banks. Concerning feeding, the authors verified that all the species preyed predominantly on arthropods (mainly aquatic insect larvae), but can also feed on fungi, plant material and other small invertebrates. Walker & Ferreira (1985) studied the population dynamics and reproductive biology of shrimp from Rio Tarumã-Mirim, a tributary of the lower Rio Negro. They found that density and species distributions varied with the annual inundation cycle and that reproduction varied with channel size. For the five species breeding in leaf litter habitats of the periodically inundated floodplain forest (igapó) associated with the large lower reach, reproduction was restricted to the period of rising and peak water levels, whereas the same species occurring in the narrower and more stable upper reaches bred year round. In the same tributary, Henderson & Walker (1986) studied the composition and trophic structure of the faunal community that inhabits submersed litter and verified that shrimps were the dominant invertebrate group. Also in the Rio Tarumã-Mirim, Walker (2001) investigated the distribution patterns of two sibling species of *Euryrhynchus*, verifying that *E. burchelli* was dominant in the lower reach and *E. amazoniensis* was the exclusive species in the uppermost reach within the closed-canopy inundation forest. The author attributed the coexistence of the two species in the lower reach to non-random population dynamics and intra-specific competition.

The reproductive strategies of several Amazonian shrimps, including those of upland forest streams, have been investigated. Magalhães & Walker (1988) compared the newly-hatched larva of six Central Amazonian species which presented three different types of larval development (complete, abbreviated and direct) and suggested that the abbreviated metamorphosis with direct development arose due to the high selective pressure associated with plankton-poor waters. Concerning the distinct life history traits of these species, Walker (1992) discussed their phylogenetic convergence (several genera developing the same adaptive pattern independently) and divergence (the same genus/species exhibiting different patterns in different environments) in relation to general molecular genetics. Odinetz Collart & Enriconi (1993) focused their study on *Palaemonetes carteri* found in periodically inundated floodplains some tributaries of lower Rio Negro. They also found that the reproductive period of this species was restricted to the rising and high water seasons. Odinetz Collart & Magalhães (1994) reviewed research on reproductive strategies of shrimp from different Amazonian environments, and concluded that discharge variation and plankton production represent the main ecological constraints for species and community evolution. García-Dávila et al. (2000) verified that *Macrobrachium brasiliense* from forest streams in the Peruvian Amazon had continuous reproduction along the year, with a peak between April and June.

The objective of the present study was to investigate the influence of spatial variation in river channel characteristics and habitat structure on the abundance and community structure of shrimps and crabs in headwaters streams of the Rio Jaú.

Material and Methods

Study area - The Rio Jaú is an eighth order black water tributary of the Rio Negro, located between the cities of Moura and Novo Airão in the state of Amazonas, Brazil. This river is 300 km long and drains 10,000 km^2 of largely undisturbed lowland tropical forest growing on Tertiary sediments of fluvio-lacustrian origin (Sioli 1984). The Jaú basin is completely enclosed in the Jaú National Park (FVA/IBAMA 1998). The climate in the study region is humid tropical with temperatures varying between 22 and 33^{o}C and annual rainfall varying between 1,700 and 2,500 mm. Rainfall is seasonal with a distinct rainy period extending from November to June and a dry period extending from July through October. Rainfall is heaviest in March, with a monthly average of 350 mm, and lightest in November, with an average of 140 mm (FVA/IBAMA 1998). Thirty-four headwater streams of the Rio Jaú were sampled in the present study (Fig. 1). Most were acid black water streams with high concentrations of humic and fulvic acids derived from sandy hydromorphic podsols (Marien 1995). However, there were also a small number of less acid clear water streams, which drained predominantly lateritic soils and had much lower concentrations of organic acids (Leenheer 1980). The pH of the study streams varied from 3 and 5.5, water temperature varied between 23 and 26 ^{o}C, channel width ranged between 0.3 and 8.0 meters and channel depth varied from 0.3 to 1.7 meters.

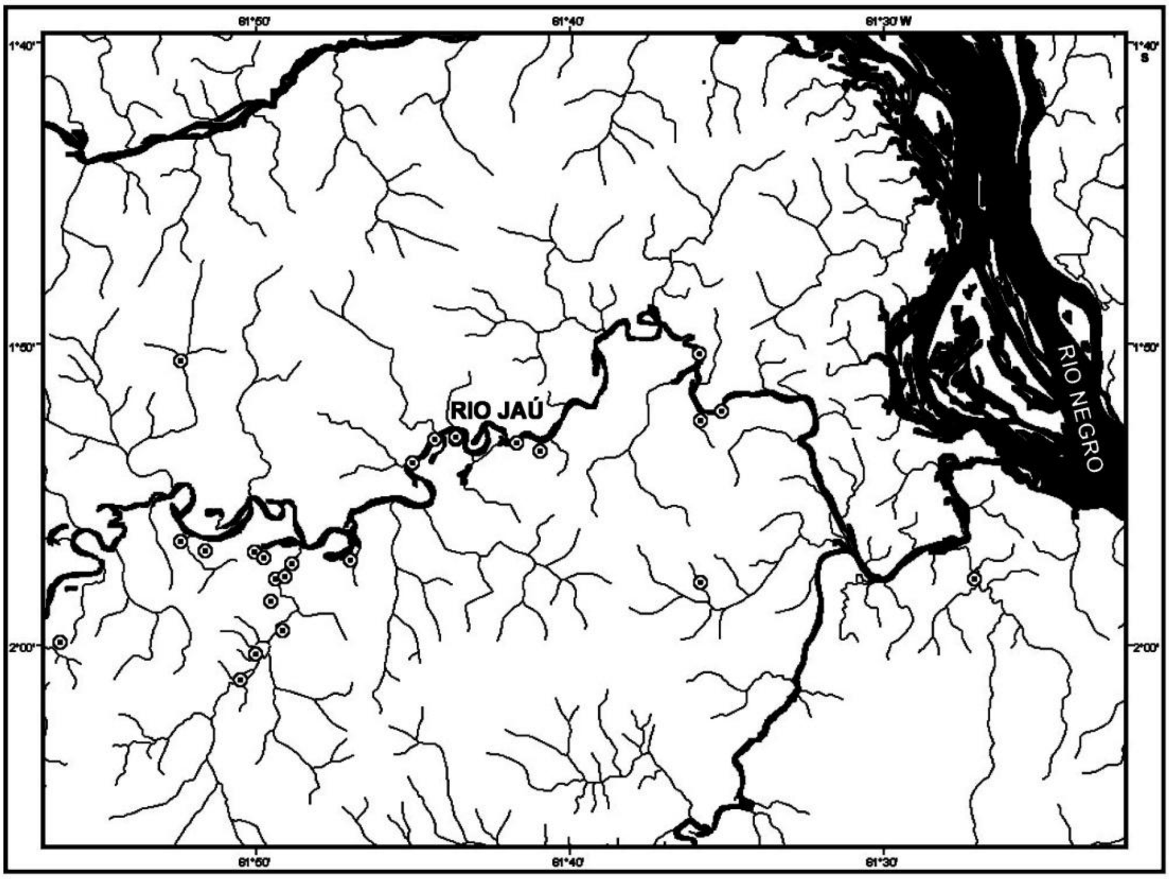

Fig. 1. Location of 34 headwater stream reaches sampled in the Rio Jaú Basin, Central Amazon, Brazil.

Sampling methods - Samples were collected and measurements made in all streams between November 1 and December 31 of 1998 which corresponded to the low water period. Biological collections and measurements of habitat distributions and channel morphometry were made along a standard sampling reach containing two complete meanders to guarantee that most stream habitats would be well represented. Water quality parameters (dissolved oxygen (O_2), temperature, pH and conductivity) were determined at a central point along the sampling reach. Dissolved oxygen O_2

concentrations and temperature were determined with a Yellow Springs Instrument model 58 polarographic oxygen probe/thermister. Conductivity was estimated with VWR portable conductivity meter (model 2052), and pH was determined with an Orion model 510 pH meter equipped with a Ross type probe for low ionic strength waters. Channel width was measured along ten equidistant lateral transects with the aid of a measuring line. Water discharge was estimated at the central transect from depth and width integrated point measurements of current speed. Current speed was estimated with a General Oceanics Inc., Ott type, current meter. Stream depth and bottom substrate were also determined at 0.1 m intervals across each transect. Bottom substrates were classified in six categories: leaves, sand, trunks, mud, roots and rocks. Data on bottom substrates from all transects were used to estimate the average percentage of each substrate cover.

Both hand dip nets and traps were used to collect shrimp and crabs. The traps, fabricated from two liter PET bottles, were cylindrical with a single conical entrance. Twelve shrimp traps, baited with meat, were distributed randomly along each sampling reach and exposed for 24 hours. After removing the traps, 30 random samples were collected along the same section with a dip net. A single aggregated sample, including decapods from all traps and nettings was obtained for each reach and stored in a 100 ml glass jar in 70% alcohol. Decapods were anesthetized with dissolved ether before killing to reduce suffering. Voucher specimens of each species collected were deposited in the Crustacean Collection of the Instituto Nacional de Pesquisas da Amazônia, Manaus, Brazil. The sum of al trappings and netting for each reach was considered a single unit of effort and the aggregated number or biomass of crustaceans collected was considered the total catch per unit of effort (CPUE).

Data analysis - Physical, chemical and substratum variables were first analyzed with correlation matrixes to evaluate the co-variation among variables. To better identify consistent groupings among co-variables, all independent variables were then aggregated into orthogonal axes using Non-Metric Multidimensional Scaling (NMDS). Finally, all independent variables which contributed significantly to the variation in these axes were identified and their influence on decapod numbers and biomass was investigated using Simple Linear Regression (Sneath & Sokal 1973). Species associations were investigated by hierarchical clustering or dendrogram analysis, using the abundance values of all reaches as input variables for each species (Ward 1963). A standard Euclidian normalization was applied to the data which were aggregated with both simple and average group linkages.

Results

A total of 1,516 individual crustaceans were collected in all reaches belonging to three families and nine species. The shrimps species included *Euryrhynchus amazoniensis* (Tiefenbacher, 1978): Euryrhynchidae, *Macrobrachium ferreirai* (Kensley & Walker, 1982), *Macrobrachium nattereri* (Heller, 1862), *Pseudopalaemon* sp. 1, *Pseudopalaemon chryseus* (Kensley & Walker, 1982), *Pseudopalaemon amazonensis* (Ramos-Ferreira, 1979), *Palaemonetes corteri* (Gordon, 1935), and *Palaemonetes mercedae* (Pereira, 1986): Palaemonidae. The crab species was *Moreirocarcinus laevifrons* (Moreira, 1901): Trichodactylidae. The total number of individuals captured per reach varied from 6 to 90 with an average value of 44.58. The total biomass collected was 782.82 g. Biomass collected per reach varied from 1.0 to 151.4 g with an average value of 24.02 g.

The degree of co-variation among independent variables was investigated initially using correlation matrixes. For the eight physical-chemical variables used (pH, conductivity, water temperature, stream depth, stream width, water discharge and dissolved oxygen) we obtained 15 significant correlations, indicating a high degree of co-variation among them. All the physical variables of the canal presented significant correlation with dissolved oxygen, with the exception of pH. We also found four significant correlations among the percentages of the six bottom substrate types (leaf + sand, leaf + rock, rock + trunk and mud + trunk). Analyzing all independent variables together, we encountered 34 significant correlations, including interactions between the substratum and with channel morphology. To identify consistent groupings among co-variables, ordinal orthogonal axes were derived from the 14 original variables (pH, conductivity, water temperature, depth, width, discharge, DO, %sand, %leaf, % mud, % rock, % root and % trunk). Two axes explained the majority of the environmental variations encountered in these streams. The contributions of all independent variables to the variance in each of these axes are indicated in Table I. Axis one was strongly correlated with channel morphology and dissolved oxygen. It was also significantly influenced by two benthic substrate components, the percentages of leaf and sand cover. This axis represented the systematic change in canal morphology and habitats, postulated by Vannote *et al*. (1980) in the River Continuum Concept. Axis two was also significantly influenced by sand and leaf cover, however the correlations were higher and the signs (+/-) inverted. This axis represented variation in bottom substrates, independent of stream morphology. Only four of the original independent variables correlated significantly with the two orthogonal axes (channel depth, channel width, % sand cover and %leaf cover). To simplify the understanding of the final results these measured parameters were used as independent variables in the subsequent linear regression analyses.

Table I. Pearson and Kendall product-moment correlations between the 14 independent variables in two NMDS ordination axes (* significant correlations, p<0.05).

	Axis 1	Axis 2
	R	R
dissolved O_2	-0,311	0,236
air temperature	0,140	0,109
water temperature	0,235	0,063
water discharge	-0,473	0,121
Conductivity	0,062	-0,111
pH	0,016	0,117
stream width	-0,914*	-0,038
stream depth	-0,919*	0,092
% sand cover	-0,636*	0,803*
% root cover	-0,024	0,011
% mud cover	0,353	0,185
% trunk cover	0,197	0,381
% rock cover	-0,320	0,072
% leaf cover	0,552*	-0,859*

The percent sand cover in stream bottoms had a significant positive effect on total decapod CPUE when expressed as biomass and a significant negative effect on CPUE when expressed as numbers (Fig. 2a, b). The CPUE of *Euryrhynchus amazoniensis*, expressed as either numbers or biomass, decreased significantly with % sand cover (Fig. 3a, b). *Euryrhynchus amazoniensis* biomass was also found to increase significantly with % leaf cover and decline with increasing depth (Figures 3d and 3c respectively). In contrast, the CPUE (both numbers and biomass) of *Macrobrachium nattereri* increased significantly with both channel depth and width (Fig. 4a, b, c, d). The CPUE (both numbers and biomass) of *Palaemonetes corteri* also increased with both channel depth and width (Fig. 5a, b, c, d). The CPUE of *Pseudopalaemon amazoniensis* number increased with significantly (numbers) with % sand cover (Figure 6a), and also (biomass) with channel depth (Fig. 6b).

Species composition varied considerably between headwater reaches (Table II). The most common species were *Macrobrachium ferreirai* and *Euryrhynchus amazoniensis* and the rarest were *Pseudopapalaemon chryseus* and *Palaemonetes carteri*. The hierarchical clustering analysis indicated somewhat different grouping patterns when aggregate by abundance (Fig. 7a) and biomass (Fig. 7b). In both cases, Macrobrachium ferreirai was clearly separated from the remaining species. However, the grouping patterns for the other species varied considerably between analyses and were considered inconsistent.

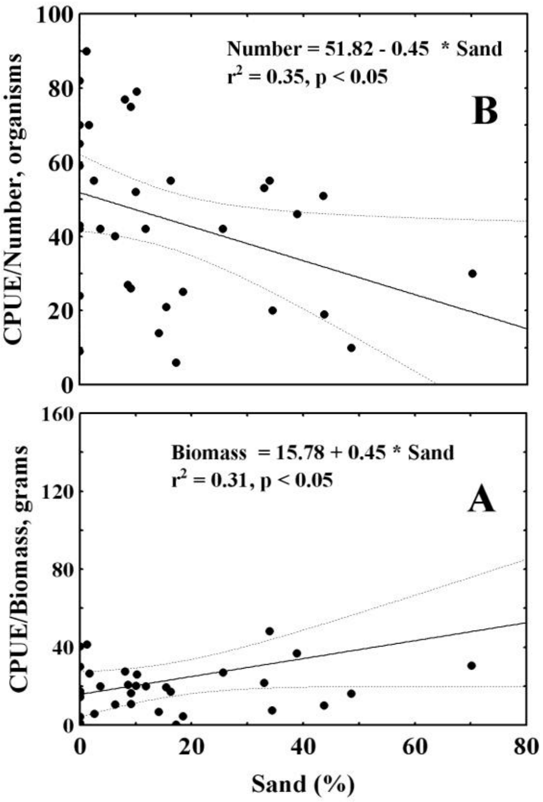

Fig. 2. Relationships between % benthic sand cover and decapod CPUE, expressed in A) numbers and B) biomass.

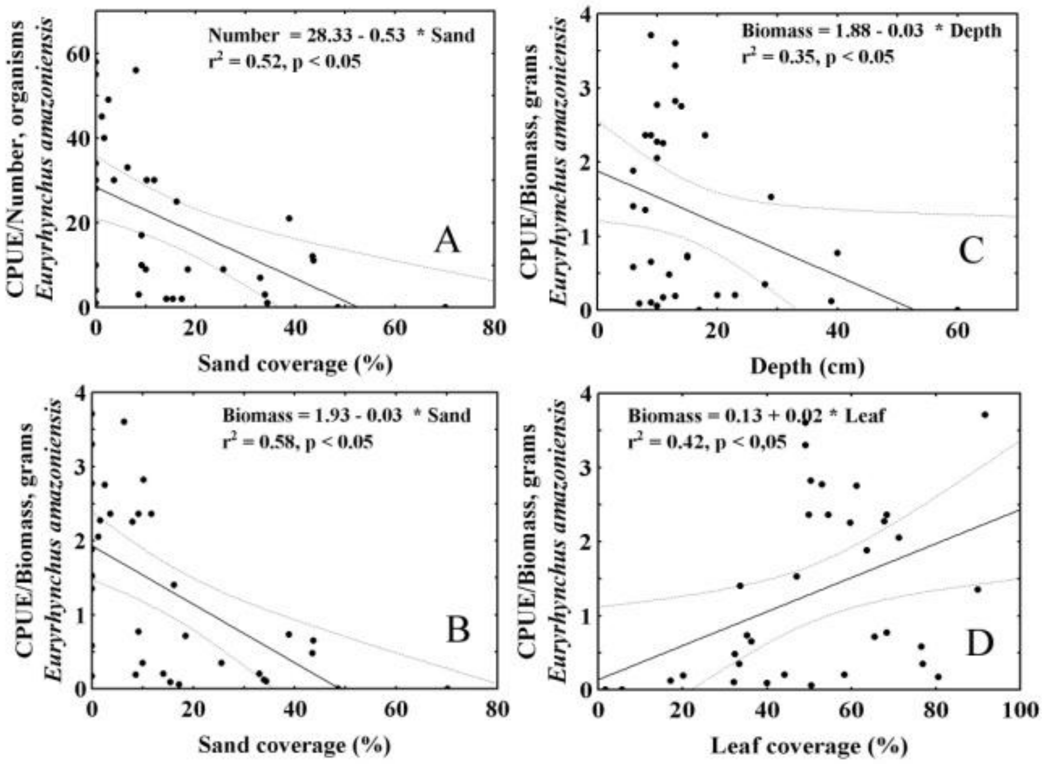

Fig. 3. Relationships between the CPUE of *Euryrhynchus amazoniensis* biomass and A) % benthic sand cover and between the CPUE of *Euryrhynchus amazoniensis* numbers and B) % sand cover, C) channel depth and D) % leaf cover.

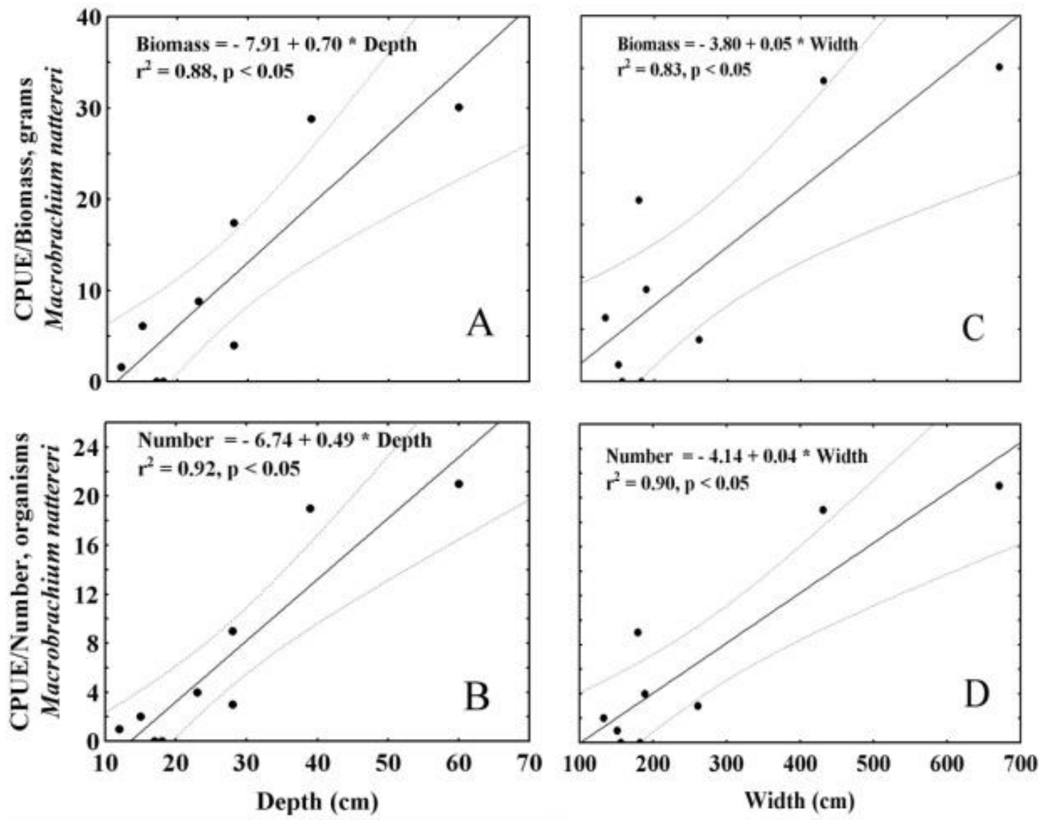

Fig. 4. Relationships between the CPUE of *Macrobrachium nattereri* biomass and A) channel depth and C) channel width and between the CPUE of *Macrobrachium nattereri* numbers and B) channel width and D) channel depth.

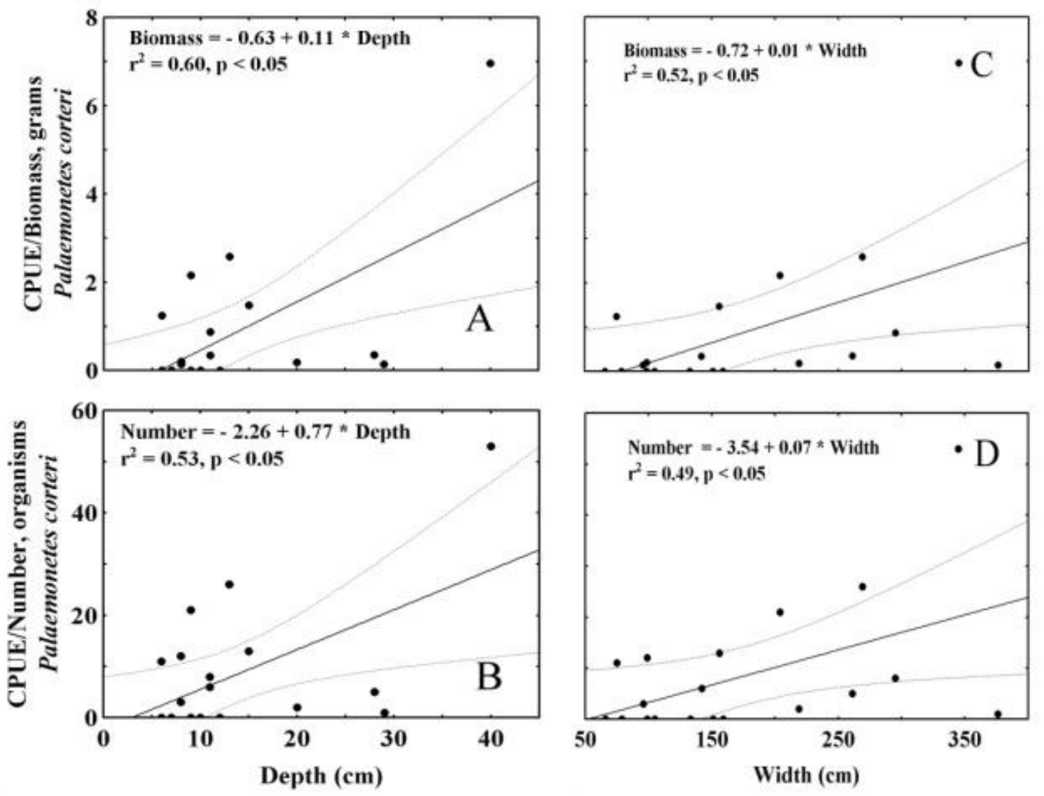

Fig. 5. Relationships between the CPUE of *Palaemonetes corteri*.biomass and A) channel depth and C) channel width and between CPUE of *Palaemonetes corteri*.numbers and B) channel width and D) channel depth.

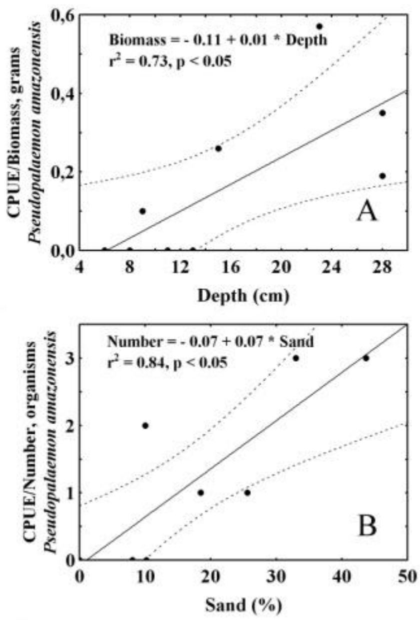

Fig. 6. Relationship between the CPUE of *Pseudopalaemon amazonensis* biomass and A) channel depth and between the CPUE of *Pseudopalaemon amazonensis* numbers and B) % sand cover.

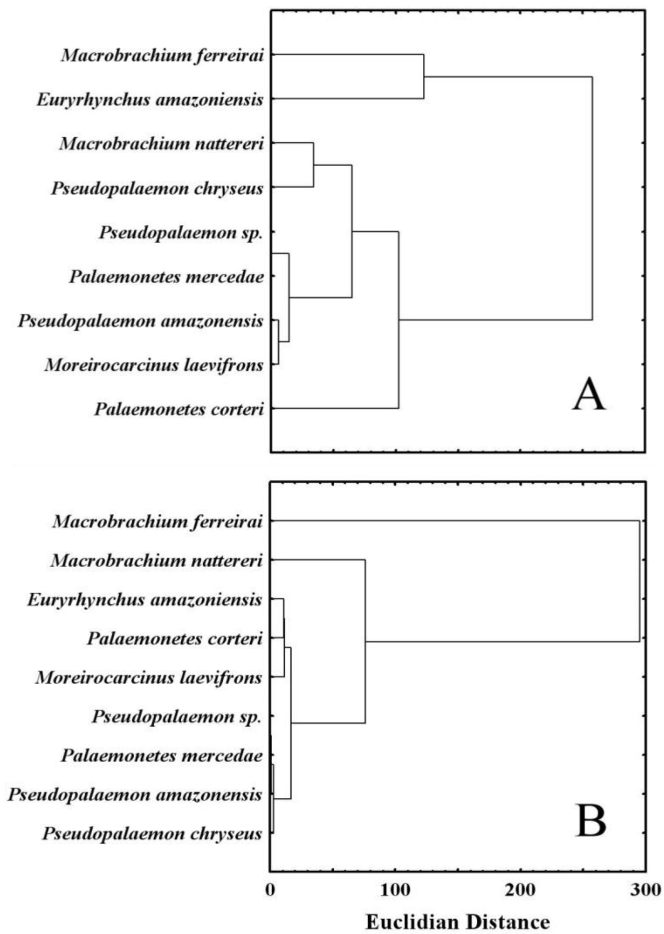

Figure 7. Hierarchical clustering of shrimp and crab species from 34 headwater streams, using A) abundance and B) biomass values with single linkage groups and standard Euclidian normalization.

Table II. Decapod species composition in headwater reaches of the Rio Jaú. [Palaemonidae: 1= *Macrobrachium ferreirai*, 2= *Macrobrachium nattereri*, 3= *Euryrhynchus amazoniensis*, 4= *Pseudopalaemon* sp. 1, 5= *Pseudopalaemon chryseus*, 6= *Pseudopalaemon amazonensis*, 7= *Palaemonetes corteri*, 8= *Palaemonetes mercedae*; Trichodactylidae: 9= *Moreirocarcinus laevifrons*]

									Species
Reach	1	2	3	4	5	6	7	8	9
1	0	21	0	0	9	0	0	0	0
2	24	0	3	0	0	0	0	0	0
3	21	19	3	0	12	0	0	0	0
4	9	9	9	0	14	1	0	0	0
5	8	4	7	0	30	3	0	1	0
6	0	0	2	0	1	0	0	3	0
7	14	3	9	1	18	2	5	0	0
8	26	0	40	0	3	0	0	1	0
9	3	0	49	0	3	0	0	0	0
10	8	0	55	0	2	0	0	0	0
11	15	0	34	0	0	0	21	0	0
12	0	0	1	0	0	0	8	0	0
13	41	0	45	0	4	0	0	0	0
14	13	0	28	0	0	0	1	0	0
15	19	0	2	0	0	0	0	0	0
16	17	0	25	0	2	0	11	0	0
17	36	1	12	0	1	0	0	0	1
18	12	0	10	0	0	0	53	0	0
19	10	0	2	0	0	0	2	0	0
20	5	0	17	0	0	0	3	0	1
21	1	0	58	0	0	0	0	0	0
22	6	0	33	0	0	0	0	0	1
23	12	0	30	0	0	0	0	0	0
24	19	0	1	0	0	0	0	0	0
25	20	2	21	0	3	0	0	0	0
26	8	0	0	0	0	0	0	0	1
27	12	0	30	0	0	0	0	0	0
28	45	0	30	0	0	0	0	7	0
29	33	0	10	0	0	0	0	0	0
30	8	0	4	0	0	0	12	0	0
31	2	0	9	0	0	1	13	0	0
32	12	0	56	0	0	0	6	0	3
33	4	0	11	0	0	3	0	0	1
34	19	0	30	0	3	0	26	0	1

Discussion

Several clear patterns are evident in these results. As predicted by the RCC, variations in channel size had a strong influence on the species composition of decapod communities in this system. Similar changes in aquatic community structure linked to longitudinal variations is stream channel morphology have been reported by other authors (Magalhães *et al.* 2002, Poully *et al.* 2005, Romanuck *et al.* 2006). Variations in benthic habitat cover also appeared to have a major effect on both the species composition and total biomass/abundance of decapod communities. Systematic variations in channel morphology along the stream size continuum of the Rio Jaú have been show to result in major changes in the distribution of benthic habitats (Forsberg *et al.* 2001) and the species composition and trophic structure of benthic macroinvertebrate communities (Cargnin-Ferreira & Forsberg 2000).

The inverse relationships encountered for decapod biomass and numbers against % sand (Fig. 2a, b) could reflect the dominance of larger and more competitive individuals for a preferred habitat or selective predation of other organisms on the slower smaller individuals in the community. The preference of the decapods for the sandy habitat was recorded by Magalhães & Pereira (2005) in forest streams in middle Rio Caura basin, Venezuela.. In this study, *Euryrhynchus amazoniensis* was abundant in shallow streams with a high % of leaf cover and low % of sand (Fig. 3), indicating a preference for leaf litter banks. The observed associations of *Macrobrachium nattereri* and *Palaemonetes carteri* with deeper and wider channels (Fig. 4 and 5) suggest that these two species explore entire water column of streams looking for food, and that benthic substrates are relatively unimportant to them.

The observed association of *Pseudopalaemon amazonensis* with deep sandy channels (Fig. 6)can be explained by the fact that these organisms tend to forage on small organisms which migrate from submerged litter banks to the sandy deeper channels at night (A. Kemenes, direct observation).

The results of this study have important implications for the management and conservation of decapod fauna in this and other tropical fluvial systems. The preservation of aquatic habitats is essential for the maintenance of the diversity and structure of aquatic communities in headwater streams. An understanding of the complex associations between individual species and habitats is essential for the development of habitat-specific conservations strategies. The degradation of habitats critical for decapod survival could result in a significant decline in the diversity and abundance of these trophically important aquatic communities.

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References

Cargnin-Ferreira, E. & Forsberg B. F. 2000. Trophic structure of macroinvertebrate communities in the Jaú River System (Central Amazon, Brazil). **Brazilian Journal of Ecology**, 3: 59-66.

Conners, M. E. & Naiman, R. 1984. Particulate allochthonous inputs: relationships with stream size in an undisturbed watershed. **Canadian Journal of Fisheries and Aquatic Science**, 41: 1473-1484.

Cummins, K. W. 1974. Structure and function of stream ecosystems. **Bioscience**, 24: 631-641.

Forsberg, B. R., Díaz-Castro, J.G., Cargnin-Ferreira, E. 2001. The structure and fuction of the Negro river ecosystem: insights from the Jaú project. Pp 125-144. *In:* Chao, N. L.; Petri, P.; Prang, G.; Sonneschien, L. & Tlusty, M. (Eds.) **Conservation and Management of Ornamental Fish Resources of the Rio Negro Basin, Amazonia, Brazil – Project Piaba**. Editora Universidade do Amazonas, Manaus, 301p.

FVA/IBAMA. 1998. **Plano de Manejo do Parque Nacional do Jaú**. Relatório Fundação Vitória Amazônica/ IBAMA, Manaus, Brazil. 108p.

García-Dávila; Alcantara B., F.; Vasquez R., E. & Chujandama S., M. 2000. Biologia reprodutiva do camarão Macrobrachium brasiliense (Heller, 1862) (Crustacea: Decapoda: Palaemonidae) em igarapés de terra firme da Amazônia peruana. **Acta Amazonica,** 30(4): 653-664.

Henderson. P.A. & Walker, I. 1986. On the leaf litter community of the Amazonian blackwater stream Tarumazinho. **Journal of Tropical Ecology**, 2: 1-17.

Kensley, B. & Walker, I. 1982. Palaemonidae shrimp from the Amazon basin (Crustacean: Decapods: Natantia). **Smithsonian Contribution to Zoology**, 362: 1-28.

Leenheer, J.A. 1980. Origin and nature of humic substances in the waters of the Amazon River basin. **Acta Amazonica**, 10: 513-526.

Magalhães, C. & Pereira, G. 2005. Decapods crustaceans' survey in the middle Río Caura basin: species richness, habitat, zoogeographical aspects, and conservation implications. Pp. 56-63. *In:* Riseng, K., Chernoff, B., Machado-Allison, A., Montambault, J.R. (Eds.), **An Aquatic Biological Assessment of the Aquatic Ecosystems of the Río Caura Basin, Venezuela**. Conservation International, Washington, 284 p.

Magalhães, M. F., Batalha, D. C. & Collares-Pereira, M. J. 2002. Gradients in stream fish assemblages across a Mediterranean landscape: contributions of environmental factors and spatial structure. **Freshwater Biology**, 47: 1015–1031.

Magalhães, C. & Walker, I. 1988. Larval development and ecological distribution of Central Amazonian palaemonid shrimps (Decapoda: Caridea). **Crustaceana**, 55(3): 279-292.

Marien, J. A. S. 1995. Comunidades de camarões em duas reservas da Amazônia Central: Parque Nacional do Jaú e Estação Ecológica de Mamirauá. **Master Dissertation**. Instituto Nacional de Pesquisas da Amazônia, Manaus, 84 p.

Minshall, G.W.; Petersen, R.C.; Cummins, K.W.; Bott, T.L.; Sedell, J.R.; Cushing, C.E.; Vannote, R.L. 1983. Interbiome comparasion of ecossystem dynamics. **Ecological Monographs**, 53: 1–5.

Odinetz-Collart, O. & Enriconi, A. 1993. Estratégia reprodutiva e alguns aspectos demográficos do camarão *Palaemonetes corteri* (Gordon, 1935) na Amazônia central, rio Negro. **Acta Amazonica**, 23 (2-3): 227-243.

Odinetz-Collart, O. & Magalhães, C. 1994. Ecological constraints and life history strategies of palaemonid prawns in Amazonia. **Verhandlungen Internationale Vereinigung für theoretische und angewandte Limnologie**, 25: 2460-2467.

Pouilly, M., Barrera, S. & Rosales, C. 2005. Changes of taxonomic and trophic structure of fish assemblages along an environmental gradient in the Upper Beni watershed (Bolivia). **Journal of Fish Biology**, 68: 137–156.

Romanuk, T. N., Jackson, L. J., Post, J. R., McCauley, E. & Martinez, N. D. 2006. The structure of food webs along river networks. **Ecography**, 29: 3-10.

Sioli, H. 1984. The Amazon and its main effluents: Hydrography, morphology of the river courses, and river types. Pp. 127-166 In: Sioli, H. (eds). **The Amazon limnology and landscape ecology of a mighty tropical river and its basin**. The Hague, W. Junk Publications, Netherlands. 763 p.

Sneath, P.H.A. & Sokal, R.R. 1973. **Numerical Taxonomy**. W.H. Freeman & CO, San Francisco.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. & Cushing, C.E. 1980. The river continuum concept. **Canadian Journal of Fisheries and Aquatic Sciences**, 37: 130-137.

Walker, I. 1985. On the structure and ecology of the microfauna in the Central Amazonian forest stream igarapé da Cachoeira. **Hydrobiologia**, 122: 137-152.

Walker, I. 1987. The biology of streams as part of Amazonian forest ecology. **Experientia**, 43: 279-287.

Walker, I. 1990. Ecologia e biologia dos igapós e igarapés. **Ciência Hoje**, 11 (64): 46-52.

Walker, I. 1992. Life history traits of shrimps (Decapoda: Palaemonidae) of Amazonian inland waters and their phylogenetic interpretation. **Studies on Neotropical Fauna and Environment**, 27: 131-143.

Walker, I. 2001. The pattern of distribution of the two sibling species *Euryrhynchus amazoniensis* and *E. burchelli* (Decapoda, Palaemonidae) in the Central Amazonian blackwater stream Tarumã-Mirim, and the problem of coexistence. **Amazoniana**, 16(3/4): 565-578.

Walker, I. & Ferreira, M.J.N. 1985. On the population dynamics and ecology of the shrimp species (Crustacean, Decapoda) in the Central Amazonian river Tarumã-Mirim. **Oecologia**, 66: 264-270.

Walker, I., Henderson, P.A. & Sterry, P. 1991. On the patterns of biomass transfer in the benthic fauna of the amazonian black-water, as an evidenced by 32P label experiment. **Hydrobiologia**, 215: 153-162.

Ward, H.H. 1963. Hierarchical grouping to optimize and objective function. **J. Amer. Stat. Assoc**. 58: 236-244.

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