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SPATIAL VARIABILITY OF BIOTIC AND ABIOTIC FACTORS OF THE AQUATIC HABITAT IN FRENCH GUIANA

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ABSTRACT

Research on tropical fish ecology in South America is focused mainly on the effect of environmental variables on aquatic organisms. Physical, chemical and biological characteristics of water measured at a local scale (local variables) are used, although geomorphological and hydrological factors measured at a regional scale (regional variables), as well as temporal and spatial heterogeneity, can also be considered. However, the use of this multi-scale approach increases the perceived complexity, heterogeneity and variability of rivers. Thus, it is important to determine the magnitude of habitat variability and those parameters having the greatest influence on it. In this study, 28 stations distributed on 16 different rivers in French Guiana were sampled during high water at a meso spatial scale. Physical features of the rivers were sampled along an 800-m stretch, where nine transversal transects were established on the main channel. At each river, 17 local and six regional variables were measured. Local variables relating to the physical characteristics of the channel bank and main channel and regional variables characterizing the whole basin and the position of the station in the basin were qualitatively and quantitatively described. All variables were submitted to multivariate analysis in order to determine their relative contribution to total variance. Two quantitative regional variables (*drainage area upstream from station* and *river drainage basin*), five quantitative local variables (*channel width*, *water temperature*, *channel depth*, *Secchi transparency* and *conductivity*) and one qualitative local variable (*channel substrate*) were shown to differentiate the 16 rivers sampled. This result shows the poor contribution of qualitative variables compared with quantitative ones. Gradual change in qualitative variables is probably responsible for this poor contribution to the total variance; thus, the use of such variables is not possible for spatial habitat differentiation in this study. Copyright © 2001 John Wiley & Sons, Ltd.

KEY WORDS: channel depth; channel substrate; channel width; conductivity; drainage area; multi-scale; Secchi transparency; temperature

INTRODUCTION

Research on tropical fish ecology in South America emphasizes the influence of environmental variables on aquatic biota (e.g. Lowe-McConnell, 1975; Mérona, 1986; Goulding, 1993; Rodríguez and Lewis, 1994; Mérigoux *et al.*, 1998; Tejerina-Garro *et al.*, 1998). In most of these cases the physical, chemical and biological characteristics of water were measured at a local scale and related to aquatic fauna. However, at the regional scale, physical environmental variables of the river such as channel geomorphology and hydrology can also be considered. These latter variables structure aquatic communities because they control the structure and dynamics of the river and consequently change the habitat available for organisms (Norris and Thoms, 1999). Measuring variables at a local and regional scale while considering a spatial dimension is one way of gaining an understanding of the dependency of aquatic organisms on the environment (Décamps and Izard, 1992). It has also been demonstrated that, besides primary abiotic factors, spatial habitat heterogeneity plays an important role in structuring communities of aquatic organisms (Mérigoux *et al.*, 1999).

Despite this, few studies of tropical rivers consider in their sampling protocol environmental variables measured at a local and regional scale and temporal or spatial habitat heterogeneity. This situation may be related to the intrinsic high complexity, heterogeneity and variability displayed by rivers (Décamps and

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Izard, 1992). The perception of such factors is increased by the use of a multi-scale approach (Baudry, 1992). In effect, the complex interactions among environmental factors lead to characteristic spatial habitat heterogeneity (Scarsbrook and Townsend, 1993) and variability (Hawkins *et al*., 1993). Heterogeneity and variability are also dependent on the spatial resolution being considered, i.e. is micro, meso or macro spatial scale (Walling and Webb, 1992). In addition, biotic and abiotic factors often display gradual rather than discrete variation. Finally, habitat complexity cannot be described by one single factor (Hawkins *et al*., 1993).

Despite the importance of including spatial heterogeneity in order to gain an understanding of the relationships between biological communities and the environment, there is a lack of real data on the subject. The problem is if one wants to demonstrate relationships between habitat and biological communities, one must determine the scale on which the habitat is variable and which are the most important parameters. This paper examines the spatial variability of some local and regional biotic and abiotic factors at the meso habitat scale, sampled along stretches, corresponding to a 'reach' (see Imhof *et al*., 1996), in 16 rivers in French Guiana.

METHODOLOGY

Study area

Data used in this study were sampled from 28 stations distributed along 16 different rivers (Table I) of eight basins in French Guiana (Figure 1). Most stations are located on rivers running entirely through rainforest areas, with the exception of stations 6, 13, 20 and 21 where savanna areas are also present. However, characteristic riparian vegetation exists along all rivers sampled. Stations 1, 14, 15, 18 and 19 are located near small towns. Samplings in all stations were conducted during the same hydrological season, i.e. high waters.

Scale and environmental variables

In order to determine the physical features of the river sampled, we follow the hierarchical linear spatial scale proposed by Imhof *et al*. (1996) for characterization of watershed ecosystems. The 'reach' hierarchy (10^1–10^4 m) was chosen for the evaluation and measurement of qualitative and quantitative variables at a local scale (here named local variables). In each of the 16 rivers sampled, nine main channel transects

Table I. List of river stations sampled at French Guiana

Number	Station	Number	Station
1	Camopi River	15	Maroni River downstream
2	Comté River upstream	16	Orapu River upstream
3	Comté River downstream	17	Orapu River downstream
4	Sinnamary River at Saut Dalle	18	Oyapock River upstream
5	Grand Inini River	19	Oyapock River downstream
6	Karouabo River	20	Passoura River
7	Sinnamary River at Karenrock	21	Du Père River
8	Kounana River upstream	22	Petit Inini River
9	Kounana River downstream	23	Sinnamary River at Deux Roro
10	Koursibo River	24	Sinnamary River at Sauligner
11	Maroni River at Langa Tabiki	25	Inini River
12	Leblond River	26	Sinnamary River at Takari Tanté
13	Malmanoury River	27	Tampock River
14	Maroni River upstream	28	Sinnamary River at Venus

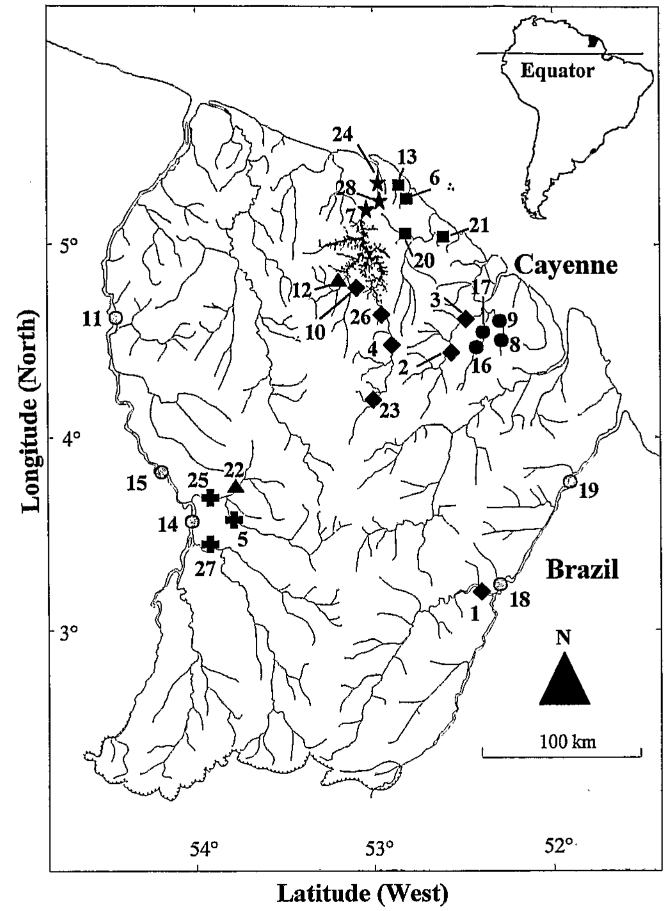

Figure 1. River stations sampled at French Guiana. Each station is numbered and assigned a symbol depending on which cluster group they belong to (▲ = Cluster 1; ★ = Cluster 2; ■ = Cluster 3; ✚ = Cluster 4; ◎ = Cluster 5; ◆ = Cluster 6; ● = Cluster 7). Refer to Table I for the names of rivers. The grey patch represents the reservoir of Petit Saut dam

were established long an 800-m stretch. At each transect, local habitat variables relating to the physical characteristics of the channel bank were measured. These were *riverside slope*, *slope pedology*, *riparian vegetation height*, *riparian vegetation cover* over the main channel and *channel width*. The first four variables were estimated and the last was measured by a range finder (Model 400™, RANGING Co.). Only the average channel width was used for statistical analysis. In the main channel at each transect, the presence/absence of *macrophytes*, *floating vegetal debris* and *coarse vegetal debris* (tree trunks) was noted. The type of *channel substrate* was determined using an Eckmans' drag. *Channel depth* was measured using a digital sounder (Speedtech Model SM-5, HONDA Electronics Co. Ltd) and the *channel flow* velocity was measured using a digital flow meter (Model 2030, General Oceanic Inc.). Type of substrate, channel depth and channel flow were determined at three or five points along each transect, depending on the channel width. However, only channel depth and channel flow values measured at the centre of the river were considered for statistical analysis. At the centre of each stretch, at a depth of 1 and 2 m, the *dissolved oxygen*, *conductivity* and *temperature* were measured using a digital meter (Model 85, YSI Incorporated). The *pH* was determined using a hand-held meter (Model pH330, WTW France), the *water transparency* with a Secchi disk, and the *turbidity* with a turbidity meter (Model 2008, LaMOTTE Co.).

The 'subwatershed' (10^4–10^8 m) and 'watershed' (10^5–10^{10} m) hierarchy (Imhof *et al.*, 1996) were chosen to measure quantitative and qualitative variables at a regional scale (here named regional variables). In this category were included two variables characterizing the whole basin, i.e. *river drainage basin* and *sinuosity*, and three related to the position of the station in the basin, i.e. *distance from the river mouth to the station*, *presence/absence of natural steep barriers* upstream and downstream of the station and *drainage area upstream each station*. The latter is considered to be a rough indicator of discharge at the station. The variables *river drainage basin* and *distance from the river mouth to the station* were measured using the software AUTOCAD MAP (Version 2.0) and the variable *river drainage basin* was estimated on a map of French Guiana (IGN 1/500.000).

Data analysis

Local and regional quantitative and qualitative data variables were submitted to multivariate analysis using the software ADE-4 (Thioulouse *et al.*, 1997). Multivariate analysis is preferred when many variables and subjects (in this case stations) are present. Indeed, linear ordination methods allow the simultaneous treatment of related or unrelated ecological variables, each one being considered equally important at the start of the analysis, thus revealing any structure in the ecological data (Dolédec and Chessel, 1991). Factorial methods of analysis, such as principal component analysis (PCA) for quantitative variables and multiple analysis of correspondence (MCA) for qualitative variables, are adequate for determining principal axes that describe relationships between the elements present in a single matrix table (Dolédec and Chessel, 1991; Simier, 1998). Thus, qualitative variable data organized in categories (Table II) were submitted to an MCA. Only the dominant or co-dominant categories in all nine transects of each river were considered, with the aim of having only one coded variable for each station. Normalized quantitative variables (Table II) were submitted to a PCA. Significant variables of each analysis were chosen based on correlation values between variables and axes and absolute contribution to total inertia (PCA). Then, the scores corresponding to each station (column scores) of the MCA and PCA analysis were submitted to an automatic classification method: the partition cluster analysis including an initial partition. This classification method determines classes around a core (Simier, 1998). The mean of each cluster by variable was then submitted to an analysis of variance (ANOVA) in order to check mean significant differences among clusters. Pairwise comparison of Bonferroni probabilities was used to form groups of clusters with similar environmental characteristics.

Table II. Regional and local variables

	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Variables–axes correlation						
Coarse vegetal debris	0.91					
Riverside slope	0.91					
Riparian vegetation height	0.89					
Slope's pedology	0.89					
Channel substrate		0.74	0.72	0.76	0.79	0.59
Macrophytes		0.56				
Riparian vegetation cover						0.74
Sinuosity		0.66				
Statistics for the six axes						
Fraction of relative inertia explained (%)	14.1	11.6	8.8	7.6	7.5	6.8
Relative inertia explained by six axes (%)			56.4			

Categories for qualitative variables are indicated.

RESULTS

Of the 11 qualitative variables used in the MCA analysis, eight local and three regional, eight showed correlation with six selected axes, which explains 56.4% of relative inertia (Table III). PCA displayed eight variables, among the 11 quantitative local and regional variables considered, with significant absolute contribution to four selected axes, which explains 78.6% of the relative inertia (Table IV). The cluster analysis carried out on the 28 sampled stations, numbered according to Table I, resulted in the following seven groups:

Table III. Summary statistics of the MCA

Scale	Type	Variable	Category
Regional	Qualitative	Natural steep barriers upstream from station	Absence, presence
		Natural steep barriers downstream from station	Absence, presence
		Sinuosity	Low, medium, high
	Quantitative	Drainage area upstream from station (km^2)	—
		River drainage basin (km^2)	—
		Distance from station to river mouth (km)	—
Local	Qualitative	Riverside slope	Steep, step-slope, step-flat, gentle slope, flooded slope
		Riparian vegetation height	Absent, low, medium, tall, flooded
		Riparian vegetation cover	Absent, low, medium, high, flooded
		Riverside slope pedology	Rock, sand, clay, soil, flooded
		Macrophytes	Absence, presence
		Floating vegetal debris	Absence, presence
		Coarse woody debris	Absent, low, medium, strong
		Channel substrate	Rock, pebbles, sand, silt, litter, clay
	Quantitative	Channel depth (m)	—
		Channel flow velocity (cm/s)	—
		Channel width (m)	—
		Conductivity (μs)	—
		Dissolved oxygen (mg/L)	—
		pH	—
		Secchi transparency (cm)	—
		Water temperature (°C)	—

Table IV. Summary statistics of the PCA

	Axis 1	Axis 2	Axis 3	Axis 4
Absolute contribution of variables				
Conductivity				3851 (0.65)
Channel flow velocity				3695 (0.64)
Channel depth			4015 (0.70)	
Channel width	1818 (0.84)			
Water temperature		3342 (0.90)		
Secchi transparency			3950 (0.70)	
Drainage area upstream from station	2172 (0.92)			
River drainage basin	1924 (0.87)			
Statistics for the four axes				
Fraction of relative inertia explained (%)	35.5	22.1	11.0	10.0
Relative inertia explained by four axes (%)		78.6		

Correlation values between variables and axes are indicated in parentheses.

- Cluster 1—stations 12 and 22
- Cluster 2—stations 7, 24 and 28
- Cluster 3—stations 6, 13, 20 and 21
- Cluster 4—stations 5, 25 and 27
- Cluster 5—stations 11, 14, 15, 18 and 19
- Cluster 6—stations 1, 2, 3, 4, 10, 23 and 26
- Cluster 7—stations 8, 9, 16 and 17

The ANOVA shows significant differences among the clusters (Table V) for local variables, such as *conductivity*, *water temperature*, *water transparency*, *channel depth*, *channel width* and *channel substrate*, and for regional variables, such as *drainage area upstream from station* and *river drainage basin*.

Quantitative variables related to first PCA axis, such as *drainage area upstream from station*, *river drainage basin* and *channel width*, present the largest average values at cluster 5 (44 318.09 km^2, 50 226 km^2 and 205.90 m, respectively). Clusters 2, 4 and 6 display values ranging between 2263.30 and 6167.04 km^2 for *the drainage area upstream from station*, between 5320.89 and 6583.75 km^2 for whole *river drainage basin* and between 54.21 and 89.72 m for *channel width*. The lowest values are present at clusters 1, 3 and 7: between 342.82 and 1094.39 km^2 for *drainage area upstream from station*, between 611.95 and 1097.4 km^2 for *river drainage basin* and between 26.59 and 31.2 m for *channel width* (Figure 2(A), Table V).

In the second PCA axis, the variable *water temperature* displays the highest mean value at cluster 2 (27.54°C), intermediate mean values at clusters 3, 4 and 5 (26.97, 26.32 and 25.71°C, respectively), and low mean values at clusters 1, 6 and 7 (24.83, 24.55 and 24.55°C, respectively) (Figure 2(B), Table V).

In the third axis, clusters 2–6 display mean values of *channel depth* varying between 4.3 and 5.52 m, whereas clusters 1, 4 and 7 display low values (3.26, 3.72 and 3.11 m, respectively) (Figure 2(C), Table V). In the same axis, *water transparency* is organized in three groups. The first is formed by cluster 1 (27.31 cm), the second is formed by clusters 4–7 (68.85, 57.86, 81.47 and 89.98 cm, respectively), and the third is formed by clusters 2 and 3 (127.08 and 173.42 cm, respectively) (Figure 2(D), Table V).

In the fourth axis, four cluster groups for *conductivity* are observed. The first is formed by clusters 1 and 4 (33.77 and 39.32 μs, respectively), followed by cluster 2 and 3 (33.71 and 31.18 μs, respectively), clusters 5 and 6 (23.59 and 25.64 μs, respectively) and cluster 7 (18.71 μs) (Figure 3(A), Table V).

The variable *channel substrate* is correlated to axes 2 to 6 (Table III). Figure 3(B) displays three cluster groups according to the distribution of categories of this variable. The first group is formed by cluster 4, where 'sand', 'silt' and 'clay' are present in the same frequency; the second group is formed by clusters 1, 3 and 7, where the category 'litter' is predominant but is associated with other categories such as sand, gravel, rock, silt and clay. The third group is represented by clusters 2, 5 and 6. In this group, the category 'sand' is predominant, but cluster 5 also presents the category 'gravel' (Figure 3(B)).

Correlation among quantitative variables is displayed in Table VI. Significant correlation is observed among quantitative local variables (*water temperature* and *dissolved oxygen*; *water temperature* and *conductivity*; *pH* and *dissolved oxygen*), among quantitative regional variables (*distance station/river mouth* and *drainage area upstream from station*; *river drainage basin* and *drainage area upstream from station*; *river drainage basin* and *distance station/river mouth*) and between regional and local quantitative variables (*channel width* and *drainage area upstream from station*; *channel width* and *river drainage basin*).

DISCUSSION

In this study, eight of the 21 quantitative and qualitative variables ordinated stations and displayed significant differences among river clusters. Two were regional variables—*river drainage basin* and *drainage area upstream from station*—and six were local variables—*channel width*, *water temperature*, *channel depth*, *water transparency*, *conductivity* and *channel flow velocity*.

Table V. Average values with minimum and maximum values in parentheses for each river cluster

Scale	Type	Variable	Cluster							
			1	2	3	4	5	6	7	
Regional	Quantitative	Drainage area upstream from station (km^2)	1094.39 (776.25–1412.54)	6167.04 (6025.6–6309.57)	807.42 (72.44–2951.21)	4683.00 (1819.70–7762.47)	44 318.09 (25 118.86–57 543.99)	2263.30 (1348.96–5888.44)	342.82 (83.18–645.65)	*
		River drainage basin (km^2)	1097.40 (775.27–1419.53)	6583.75 (6583.75)	1862.55 (88.42–7126.45)	6360.32 (4538.58–7958.63)	50 226.00 (26 820–65 830.00)	5320.89 (1342.76–6583.75)	611.95 (200.12–1023.78)	*
Local	Qualitative	Riverside slope	8.50 (8–9)	9.00 (6–13)	12.50 (5–18)	9.67 (7–13)	11.40 (6–15)	12.29 (7–17)	12.50 (10–15)	
		Riparian vegetation height (m)	9.50 (9–10)	7.00 (6–8)	13.50 (11–18)	7.67 (7–8)	8.60 (5–11)	11.29 (7–18)	9.75 (9–11)	
		Riparian vegetation cover (m)	11.50 (9–14)	9.00 (8–10)	13.25 (8–18)	13.33 (4–18)	10.00 (4–15)	9.14 (7–14)	14.00 (11–16)	
		Riverside slope pedology	13.00 (11–15)	17.67 (17–18)	15.50 (11–18)	11.33 (9–13)	13.40 (9–18)	13.86 (6–16)	17.00 (14–18)	
		Macrophytes	0.50 (0–1)	0.00 (0)	1.25 (0–4)	0.33 (0–1)	0.20 (0–1)	0.00 (0)	0.25 (0–1)	
		Coarse woody debris	1.50 (0–3)	4.67 (4–5)	3.75 (0–10)	2.33 (0–5)	3.00 (0–6)	3.57 (0–9)	1.00 (0–4)	
		Channel substrate	11.50 (10–13)	22.33 (18–30)	14.50 (10–17)	13.33 (6–18)	22.20 (20–27)	21.00 (12–31)	12.75 (10–17)	*
	Quantitative	Channel depth (m)	3.26 (2.45–4.07)	5.50 (5.25–5.75)	4.87 (3.39–7.24)	3.72 (2.88–5.25)	5.52 (4.17–6.92)	4.30 (3.39–6.31)	3.11 (2.34–4.57)	*
		Channel flow velocity (cm/s)	37.95 (30.2–45.71)	59.47 (48.98–69.18)	28.61 (6.46–46.77)	25.91 (14.45–32.36)	52.00 39.81–61.66)	54.48 (16.59–85.11)	35.91 (22.39–51.29)	
		Channel width (m)	31.20 (26.92–35.48)	89.72 (81.28–104.71)	16.15 (7.94–28.84)	78.14 (50.12–131.82)	205.90 (107.15–346.74)	54.21 (31.62–95.50)	26.59 (15.14–35.48)	*
		Conductivity (μs)	33.77 (29.51–38.02)	33.71 (31.62–37.15)	31.18 (28.84–35.48)	39.32 (37.15–43.65)	23.59 (19.05–26.3)	25.64 (23.99–26.92)	18.71 (16.22–20.42)	*
		Water temperature (°C)	24.83 (24.55–25.12)	27.54 (27.54).	26.97 (25.12–29.51)	26.32 (25.12–27.54)	25.71 (25.12–26.30)	24.55 (24.00–25.12)	24.55 (24.55)	*
		Secchi transparency (cm)	27.31 (19.95–34.67)	127.08 (109.65–151.36)	173.42 (151.36–190.55)	68.85 (39.81–89.12)	57.86 (30.20–79.43)	81.47 (77.62–95.50)	89.98 (60.25–120.23)	*

Asterisk indicates $p < 0.05$ from ANOVA among the cluster's rivers.

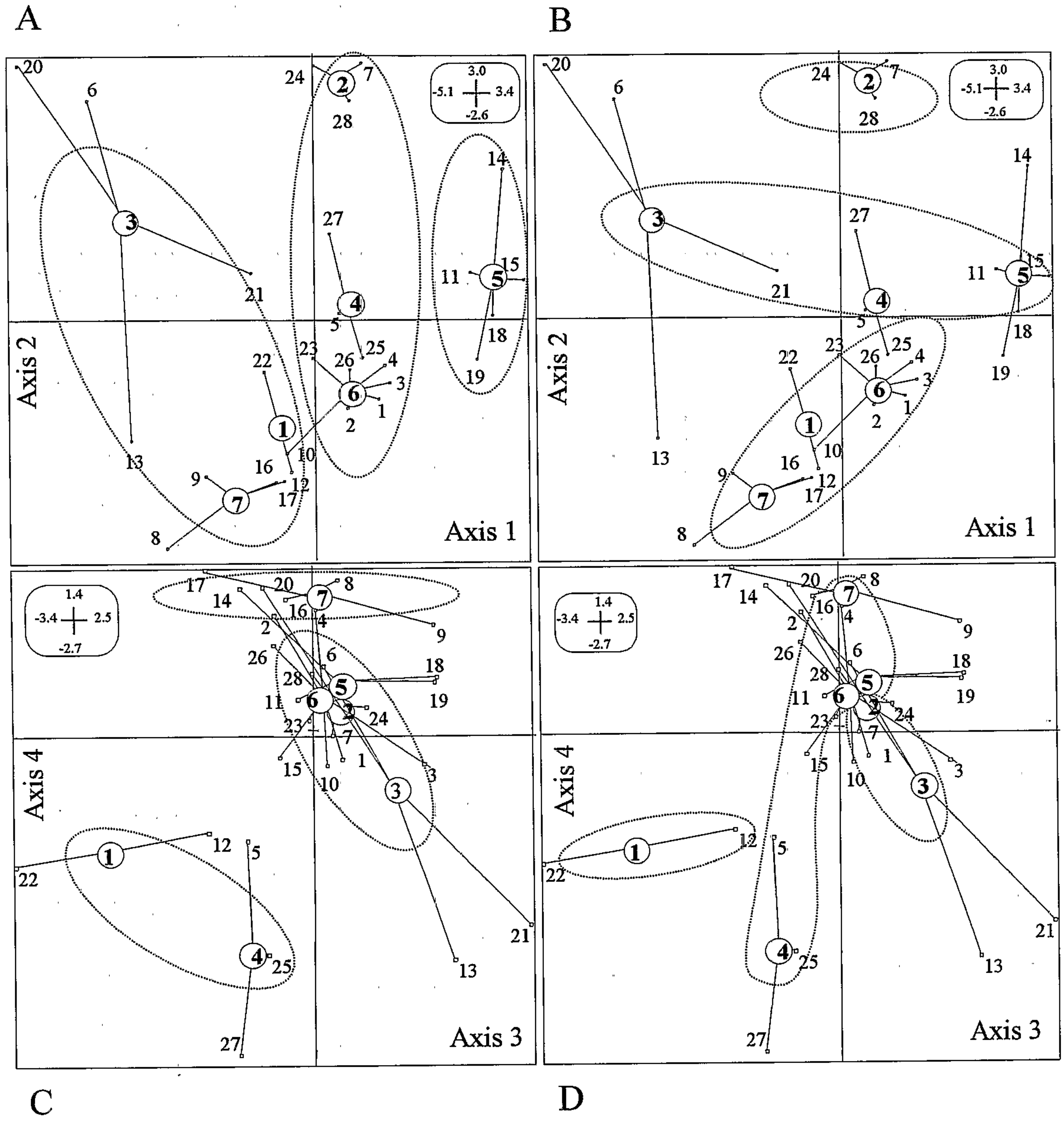

Figure 2. Scatter of stations from PCA. Inserts show dimensions of the axes. Circled numbers represent centroids of cluster groups to which the stations belong. Ellipses group clusters with similar characteristics: (A) 'whole river drainage area', 'drainage area upstream station', 'channel width'; (B) 'temperature'; (C) 'channel depth'; and (D) 'water transparency'. (A) and (B) are plotted against PCA axes 1 and 2 and (C) and (D) are plotted against axes 3 and 4

On PCA axis 1, regional variables *river drainage basin* and *drainage area upstream from station* grouped and characterized the stations sampled. The local variable *channel width* was also significant on PCA axis 1 and was correlated to the *river drainage basin* variable. The influence of variables related to the whole basin (*river drainage basin*) and to the position of the station in the basin (*drainage area upstream from station*) is not surprising because the stations were chosen in basins of different sizes. The variable *channel width* also reflects this situation. However, channel width can be locally altered by the presence of large woody debris. This biotic component increases channel width because of accumulation that causes

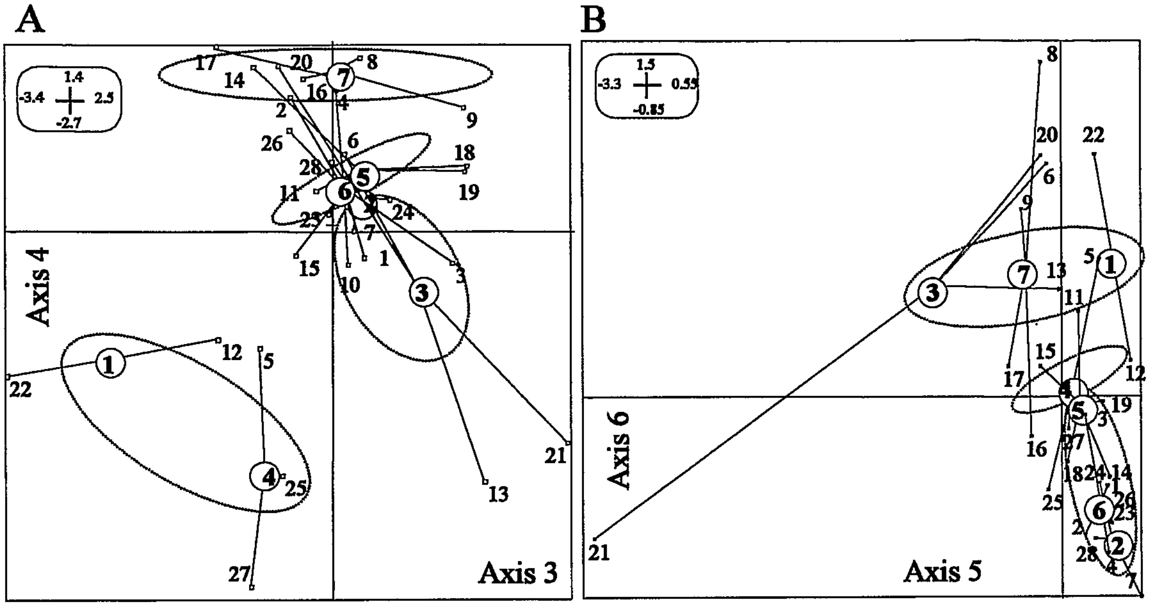

Figure 3. Scatter of stations from (A) PCA and (B) MCA. Inserts show dimensions of the axes. Circled numbers represent centroids of cluster groups to which the stations belong. Ellipses group clusters with similar characteristics: (A) 'conductivity'; and (B) 'channel substrate'. (A) was plotted against PCA axes 3 and 4 and (B) was plotted against MCA axes 5 and 6

localized flooding, erosion or diverts the river path (Baillie and Cummins, 1999; Bragg and Kershner, 1999). Nevertheless, in our study, narrow channels such as those of the rivers in cluster 1, 3 and 7 are more likely to be influenced by large woody debris than are large channels such as those of the rivers in cluster 5.

In this study, the variable *water temperature* (axis 2) displayed significant differences among the rivers sampled. This may reflect the intrinsic variance owing to the spatial scale resolution used in this study (Walling and Webb, 1992). However, differences may also result from environmental factors such as riparian shading, groundwater elevation (Walling and Webb, 1992; Poff, 1997), land use and climate (Poff, 1997). In French Guiana, some of these factors are negligible, e.g. land use (more than 90% of the territory is still covered by forest; Fritsch, 1992; Tsayem, 1998) or climate, which is equatorial and relatively constant with the temperature oscillating around 26°C throughout the year (CNRS/ORSTOM, 1979; Mérigoux *et al.*, 1998). Nevertheless, riparian vegetation shading may play an important role in temperature changes in the rivers sampled. For example, only 10% of the width of stations on the Sinnamary River, where temperatures can reach 27.54°C, is covered by riverside vegetation. These conditions promote the input of short-wave solar radiation and long-wave atmospheric radiation on the watercourse (Walling and Webb, 1992). On the other hand, stations on the rivers Kounana and Orapu, where temperatures were as low as 24.55°C, only had 52.6% of their width covered by riparian vegetation.

Channel depth had a discrete influence on the rivers sampled. This factor is almost always associated with temporal water level oscillations in either rivers (Cellot *et al.*, 1994) or lakes (Tejerina-Garro, 1996). However, temporal variation is not considered in this study and differences among rivers may be associated with other factors. Church (1992) mentioned that channel depth could be associated with channel flow velocity. In our study, rivers in clusters 5 and 6 display greater channel depths and flow velocities than do rivers in clusters 1, 4 and 7. However, other factors linked to river geological characteristics or the presence of large coarse debris that reduces flow velocity (Baillie and Cummins, 1999; Bragg and Kershner, 1999) should be considered. These may explain the differences found in rivers from cluster 3, which display flow velocity values that are incompatible with channel depth when compared with rivers in other clusters.

Table VI. Correlation values among quantitative variables

	Dissolved oxygen	Conductivity	Water temperature	pH	Transparency	Drainage area upstream station	Distance station/ river mouth	Channel depth	Channel flow velocity	Channel width	River drainage basin
Dissolved oxygen	1.00										
Conductivity	−0.27	1.00									
Water temperature	**−0.73**	**0.55**	1.00								
pH	**0.56**	−0.26	−0.48	1.00							
Transparency	−0.44	−0.03	0.36	−0.24	1.00						
Drainage area upstream station	0.48	0.10	0.08	0.17	−0.41	1.00					
Distance station/river mouth	0.17	−0.10	0.05	−0.02	−0.11	**0.53**	1.00				
Channel depth	0.11	0.04	0.14	0.05	0.25	0.48	0.19	1.00			
Channel flow velocity	0.02	−0.12	0.11	−0.08	−0.23	0.33	0.25	0.10	1.00		
Channel width	0.44	0.05	0.11	0.14	−0.37	**0.86**	0.50	0.34	0.38	1.00	
River drainage basin	0.48	0.10	−0.07	0.14	−0.34	**0.86**	**0.60**	0.38	0.27	**0.65**	1.00

Significant values are in bold.

Water transparency (PCA axis 3) sampled in this study displayed marked differences among rivers. This variable is dependent on suspended sediment. Vannote *et al.* (1980) and Walling and Webb (1992) mentioned that the quantity of sediment present in a river might decrease with increasing basin size because of numerous opportunities to deposit sediment. In this study, we did not observe this situation. River clusters distribution according to transparency seems to be related to other factors. In the case of rivers Leblond and Petit Inini (transparency cluster average = 27.31 cm), Maroni and Oyapock downstream (transparency cluster average = 57.86 cm) and Inini (transparency = 39.81 cm), transparency is affected by gold mining activities on the side bank or on the main river channel upstream of the station sampled (Figure 4). Richard (1996) identified upstream mining as the main cause of changes in water transparency in the Sinnamary River. A similar situation was revealed by Tejerina-Garro *et al.* (1998) in the Araguaia River, Amazon Basin. *Water transparency* in the rivers Kounana, Orapu (cluster average = 89.98 cm), Camopi, Comté, Koursibo (cluster average = 81.47 cm), Grand Inini and the Tampock (cluster average = 68.85 cm) is higher because of the lack of upstream anthropogenic activities. The Sinnamary River displays a special distribution of transparency values in the stations sampled. Upstream of the Petit Saut reservoir, stations display transparency values similar to rivers that are not disturbed by activities that increase sediment in water (cluster average = 81.47 cm). However, transparency in stations downstream of the reservoir displays high values (cluster average = 127.08 cm). This difference seems to be related to the sedimentation process in the Petit Saut reservoir (Richard, 1996). The coastal rivers Karouabo, Passoura, Malmanoury and Crique du Père displayed the highest water transparency values (cluster average = 173.42 cm). This situation seemed to be related to the size of the basins upstream of the sampling stations, which are small in relation to other rivers and consequently transported lower quantities of sediment.

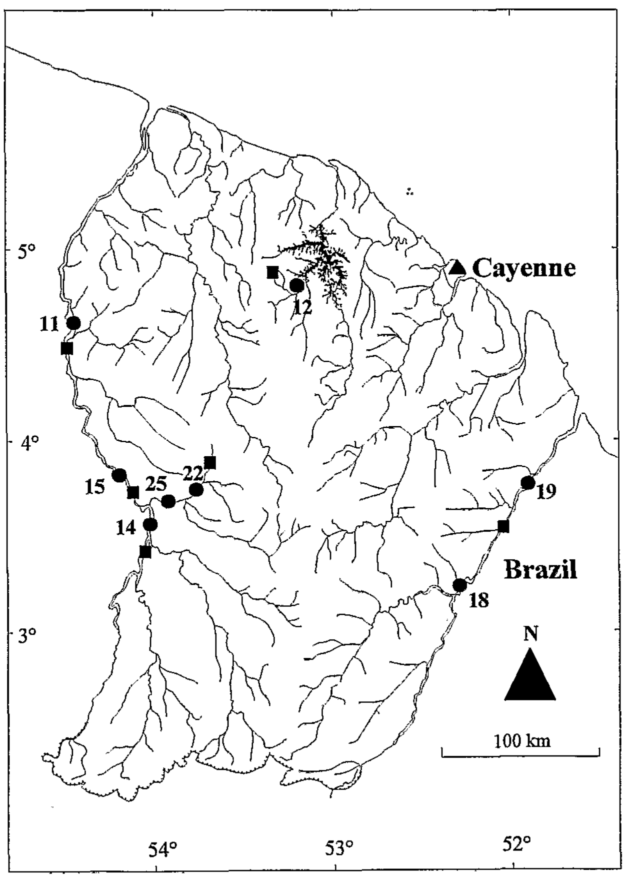

Figure 4. River stations sampled (●) where gold mining was observed (■). Gold mining on the bank side is practised at stations 12 and 22 and gold mining on the main channel is practised at other stations. Refer to Table I for the names of river stations

The distribution of variable *conductivity* (PCA axis 4) at sampling stations appeared to be more related to the liquid conductivity, which expresses a positive correlation between conductivity and temperature (Vivin, 1976) rather than to the inherent physical and chemical characteristics of those rivers. In this way, temperature and conductivity increases from rivers in cluster 7 to those in cluster 4. The exceptions are rivers in cluster 1. These display relatively high values of conductivity (33.77 μs) in relation to temperature (24.83°C). This may be the result of channel substrate mixing because of gold mining activities (F.L. Tejerina-Garro, personal observation). This process was deemed by Richard (1996) to be the cause of changes in the conductivity level at the Sinnamary River. However, differences in conductivity among the rivers sampled in this study may have other sources, such as leaching of the riverside because of floods.

Channel substrate (MCA analysis) is the only qualitative local variable that proved to be discriminant for the rivers sampled in this work. Among the factors that influence the type of channel substrate present along a river, Church (1992) mentioned channel width, flow velocity and basin drainage area. At a local scale, channel width determines the behaviour and morphology of a given section of the river (Church, 1992) and especially channel substrate. In this study, the maximum channel width in clusters 1, 3 and 7 was less than 36 m; thus, we would classify such sites/rivers as 'intermediate channel' (Church, 1992). In these intermediate channels, the presence of vegetal organic matter is frequent and substrate transport is not as active owing to weak flow. The predominant substrate component was 'litter', which was formed mainly by leaves and debris. Flow velocity was as low as 38 cm/s. The channel width of rivers in clusters 2–6 ranged between 31.62 m (minimal) and 346.74 m (maximal); they are thus classified as 'large channels' (Church, 1992). The substrate was sand or silt and flow velocity was high. This description is in accordance with our findings, i.e. the presence of sand, silt and clay and flow velocities up to 50 cm/s.

Spatial characterization of a meso habitat is not an easy task because of interactions among environmental factors and complex physical structure. Under these conditions, it is impracticable to distinguish a habitat based on one single criterion (Hawkins *et al.*, 1993). Spatial characterization can explain the numerous variables (seven in all) that the ordinate stations sampled in this study. Variation of environmental factors is often gradual rather than discrete (Hawkins *et al.*, 1993). This may explain the low contribution of qualitative variables to station characterization in this study. One additional problem is related to the poor documentation of environmental features considering spatial variation for more than one environmental factor. Moreover, this situation is not specific to Neotropical areas (Cellot *et al.*, 1994).

In this study, regional variables related to (1) basin size (*river drainage basin*), (2) position of the station in the basin (*drainage area upstream station*) and (3) local variables (*water temperature*, *channel depth*, *channel width*, *water transparency* and *channel substrate*) differentiate stations on large rivers in French Guiana. Even though regional variables were expected to ordinate stations in this study, their participation in habitat characterization allows us to validate the choice of widely separate sites (spatial variability) when analysing the relationships between habitat and aquatic communities.

Aquatic habitat features on spatial or temporal scales are important components of current ecological models such as the 'patch dynamic concept' (Townsend, 1989) or the 'habitat templet' (Townsend and Hildrew, 1994). Moreover, knowledge of environmental factors may help in the process of conservation or preservation of the environment. Thus, an increase in the number of studies considering the many local and regional variables or the effects of individual environmental factors is one way to further our knowledge about aquatic Neotropical habitats.

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