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Extent and role for fish populations of riverine ecotones along the Sinnamary river (French Guiana)

L. Tito de Morais, M. Lointier & M. Hoff
Centre ORSTOM BP 165, 97323 Cayenne Cedex, French Guiana

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Abstract

The Sinnamary is a small tropical river (250 km long, watershed of 6500 km^2) where a dam is to be impounded in 1994.

The extent of naturally periodically flooded areas along the Sinnamary river is estimated by using remote sensing (Landsat TM satellite data) and botanical groupings are described on *in situ* observations, ground truth and collections. The fish assemblages of these areas are described and their density estimated by rotenone sampling. The role of this ecotone to fish populations is discussed.

The extent of the inundated areas appears to be greater than previously estimated by classical mapping.

As expected, the fish fauna is mostly composed of fish juveniles and adults of dwarf (< 3 cm) and small (< 15 cm) species. Large predators where not found. Due to these characteristics, fish are abundant but their biomass is low in naturally inundated areas. However, juveniles of some species found only in these zones. Therefore their adult populations will probably be very sensitive to any modification of these land/water ecotones.

Introduction

Holland's definition of an ecotone (di Castri *et al.*, 1988) as used by the Scientific Advisory Committee of the UNESCO MAB programme is difficult to use 'to determine, for example, the spatial limits of the riparian ecotone' (Thorpe, 1991). In the present paper, an ecotone is the overlap zone between land and water. Along the Sinnamary it includes several types of riparian forest. Their spatial limits extend from the minimum low water mark at peak droughts to the maximum high water mark at peak floods (see Thorpe, 1991 for a detailed discussion on ecotone definitions). These limits were estimated using remote sensing techniques. Each vegetation type appears in different colours depending on its position along the gradient reaching from the permanently flooded areas (swamps) to never flooded forests (upland moist forest).

Riparian zones are known to be of great importance as providers of food resources and habitats for the freshwater fish fauna. According to temperate studies, it has been hypothesised that in response to greater availability of prey, production and abundance of fish may be greater in places that are relatively unshaded by the riparian canopy (Murphy *et al.*, 1981 and Tchaplinsky & Hartman, 1983 in Gregory *et al.*, 1991; Schiemer & Zalewski, 1992). This pattern is probably different in tropical areas where allochthonous food sources (mostly fruits, leaves, ants and other terrestrial insects) are of major importance to the fish fauna (Lowe-McConnell, 1987).

Riparian ecotones are areas of high species richness of plants and are not easily delineated (Gregory *et al.*, 1991). The mosaic structure of vegetation types is difficult to estimate by field sampling, especially in the tropical evergreen forest where access to the upper sections of rivers is often very difficult.

After ground validation and precise sampling of some selected areas along the rivers, the use of remote sensing techniques can be very useful in allowing extrapolations to larger areas of difficult access.

Remote sensing Landsat Thematic Mapper (TM) images have a low resolution of 30 x 30 m per pixel, but they have three infrared bands which are particularly suited for differentiating vegetation.

The purpose of the present study was to help answer the following questions:

- what are the different riparian plant communities along the Sinnamary river?
- do these communities have distinct species compositions and what is their species richness?
- can the surface areas of these communities be estimated by remote sensing techniques? and
- are these communities associated with specific fish assemblages and, if they are, can the importance of such associations to the fish populations be estimated?

Description of sites studied

The Sinnamary river drains the Guiana Shield in French Guiana, a department of France in north eastern South America (Fig. 1). It is a small river by South American standards (250 km in length with a watershed of 6565 km^2). A dam is under construction at Petit Saut (Fig. 2) for hydroelectric purposes. The planned reservoir will have an area of 300 km^2 and will be closed in 1994. Downstream from the dam location, the river flows mostly through the coastal plains in unconstrained reaches (Fig. 2). The section of the river upstream of Petit-Saut is a succession of rapids and small pools in constrained reaches. Upstream from the Takari-Tanté rapids (which are the upper limit of the future reservoir), there is a succession of unconstrained reaches followed by a succession of rapids and pools in constrained reaches. The headwaters are almost unexplored. Complex flood plains are never found along this river. Very few secondary channels of limited extent are found near some rapids and in some unconstrained reaches in the upper river.

The flora of the Sinnamary river basin is poorly known but this zone is considered to have a relatively low plant species richness because of the lack of high hills. Only 809 species have been inventoried among the riparian plant communities (Hoff, 1991) of the area. In contrast, over 2000 species (30% of the total Guianan flora) have been recorded from similar communities in other zones of French Guiana where collecting effort has been greater (Hoff *et al.*, 1990). The flora of the Trinité mountains on the crest line between the Sinnamary and Mana watersheds is not considered in this paper.

The ecology of the French Guiana fish fauna is still poorly known. After the historical fish 'census' of the middle of the century (Puyo, 1949), several fish surveys have been made and field guides to the fish of French Guiana have been published in the last ten years (Le Bail *et al.*, 1984; Planquette *et al.*, 1991). However, biological and ecological studies of fish are scarce. Because of the Petit Saut dam project, the Sinnamary river has received more attention and many aspects of fish ecology are under study. We have focused our studies at three sites on the upper reaches of the Sinnamary River (Figs 1 and 2): near the Takari-Tanté rapids, in the Saut-Dalles area upstream from the rapids, and in a flatter zone at 4°30′ North. In these three areas, all riparian types of vegetation of the upper part of the Sinnamary River are represented.

Geomorphology of the Sinnamary river banks is similar to other French Guiana river banks. Fluvial terraces and inundated margins are mainly made of Demerara clays in the lower reaches. The upstream zones are made of ferralitic soils on a

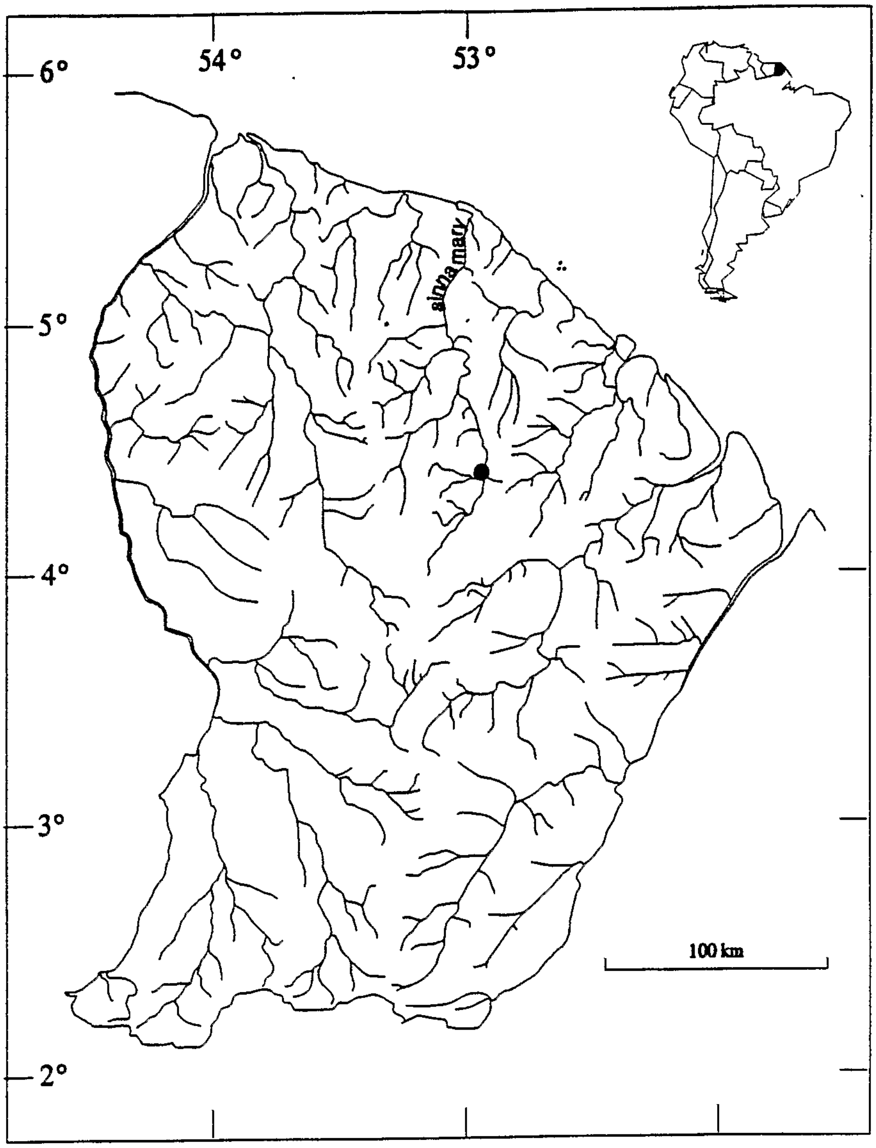


Fig. 1. Geographical position of the Sinnamary river, French Guiana, South America. Black dot indicates the study area in the upper river.

crystalline platform with alluvial terraces of coarse sediments (Blancaneaux, 1981).

Information on hydrology and water chemistry was taken from published data or obtained by other ORSTOM teams and used with permission.

The water level has been recorded continuously at Saut Dalles since November 1990, and rainfall both at Saut Dalles and in the upper basin (Laboratory of hydrology ORSTOM, Cayenne).

Material and methods

The flora

Plant assemblages in the study sites where determined by:

- direct observation and sampling of the riverine plant communities along the river margins,
- sampling along field transects perpendicular to

Table 1. Species richness of the fish fauna of five large rivers of French Guiana. Modified after Hiez & Dubreuil (1964) and Planquette *et al.* (1985), and [a] this paper, [b] Boujard *et al.* (1990a), and [c] Boujard *et al.* (1990b).

	Maroni	Oyapock	Approuague	Sinnamary	Kourou
Total fish	186	133	139	116 (126)[a]	73
Characoids	97	57 (60)[b]	62[b]	48	29
Siluriforms	52	35	–	35	25
Cichlids	17	19	–	9	5
Others	20	22	77[c]	24	14
Watershed area (km^2)	65830	26820	10850	6565	2000
River length	490	370	270	250	112

the river margins, ending, when possible, above the maximum high water mark at peak floods.
– sampling along transects parallel to the river to determine the extent of each plant assemblage.

The length of field transects was reported on maps, plants determined to species level and incorporated into the ORSTOM database.

Floristic communities have been sampled for many years in French Guiana. Over 100000 specimens have been collected, most of which are conserved in the ORSTOM herbarium in Cayenne. A database (Hoff *et al.*, 1989) includes: species name, sampling locality, geographical coordinates, date, altitude, vegetation type, plant height, and plant habit (Granville *et al.*, 1990).

This database allows the calculation, for each plant community, of the total species richness at regional and local levels (Hoff & Brisse, 1990). The calculations made for each plant community are compared with the overall distribution of each species in French Guiana given by Cremers & Hoff (1990, 1992, in press).

The extent of each vegetation type in each selected area was used to describe the ecotones where fish samplings were performed.

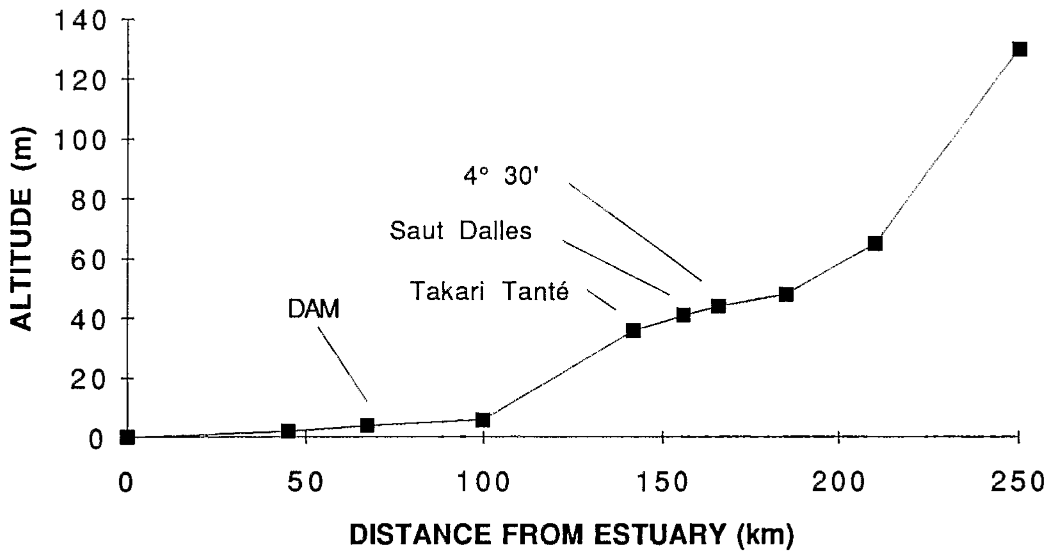


Fig. 2. Profile of the Sinnamary river with indication of the study sites and location of the dam. River length: 250 km. Watershed area: 6565 km^2. Area of the future reservoir: 300 km^2.

Remote sensing

The above floristic samplings and measurements were used as ground truth to allow for the estimation of the areas of each floristic formation at larger scales using Landsat TM images in July 1988. The image was without clouds and of excellent quality for a tropical climate.

Several classifications were tested for the best thematic results. Bands 4, 5 and 7 were then selected by Sheffield's method. A principal component analysis was performed on the three bands selected. Enhancement of colours and trichromic compositions were applied to band 7 and to the 1st principal component of bands 4 and 5 of the images taken in July 1988. Visual analysis then allowed selection of the best colour composition.

In each area (Takari Tanté rapids, Saut Dalles and 4°30′ zone) a strip of 20 pixels on each side of the river was retained for the study (Plate I). This stripe included most of the inundated and flooded areas along the river.

The percent of each floristic formation (upland moist forest, inundated forest, flooded forest, and forested and unforested swamps) was then calculated for each study area.

The fish fauna

The fish fauna was sampled by using gillnets in open formations and along the stream margin. Gillnets 25 m long and 2,2 to 2,5 m in height with mesh sizes 10, 15, 20, 25, 30, 35, 40, 50, 60 and 70 mm from knot to knot, were employed.

At each sampling, gillnets were fished for 72 h at the same place, set in the morning, and fish removed every 24 h. In inundated forest and in channels within inundated areas fish were sampled using rotenone and a 5 mm mesh net enclosing an area of 300 to 500 m^2. Each sampling session began in the morning and lasted for 4 to 6 hours. The enclosing net was left in place during the night, and the day after the remaining fish were collected.

Nine gillnet samplings were made both in the dry and wet season: twice in November 1989, and once in June, July, and December 1990, June, August and November 1991 and May 1992.

Rotenone samplings in the inundated forest and in the channels within it were performed 4 times in each area during the wet season in 1990 and 1991.

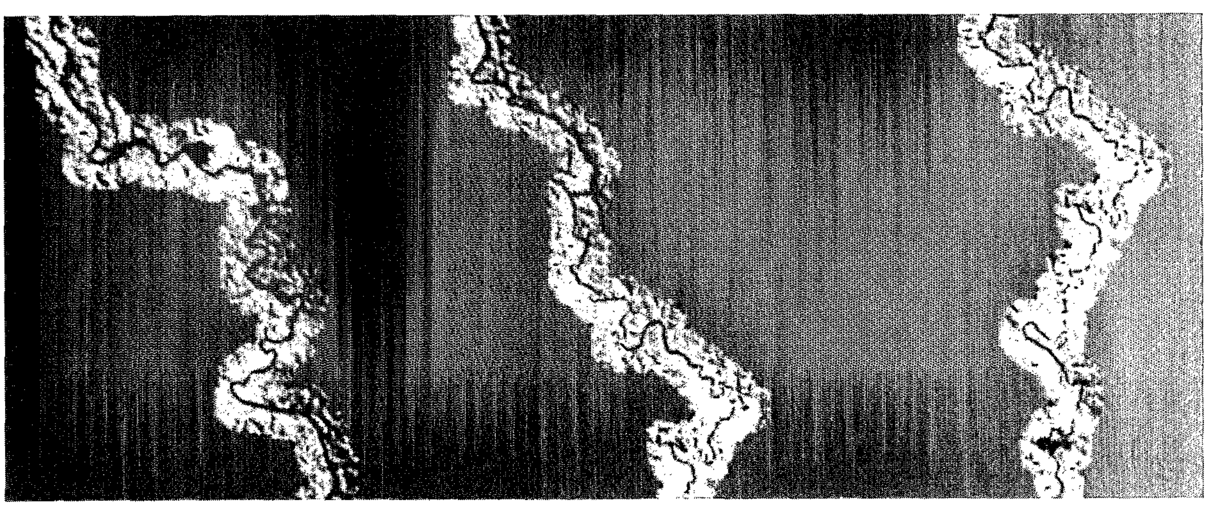


Plate 1. Remote sensing Landsat TM images (INPE/Brazil and C. Charron, remote sensing unit at ORSTOM Cayenne). Right: 4°30′ zone, center: Saut Dalles, left: Takari Tanté rapids. Vegetation types: upland moist forest (originally green pixels), flooded and swamp forest (originally blue pixels), forested and unforested swamps (originally orange and white pixels).

The fish were identified, weighed to the nearest 0.1 g and their length measured to the nearest mm.

Results

Hydrology

Inundation of the flooded forests started when water level reached 2.40 m at Saut Dalles (Fig. 3). Short periods (less than 3 days) associated to water levels at Saut Dalles lower than 2.40 m still allow the forest flooding in the sites studied.

In 1991, 52 days of flooding of the forest where recorded. Eleven high water peak floods over 2.4 m at Saut Dalles where observed from 1 January to 4 August. Most of the peaks lasted only for very short periods (1 to 8 days). The longest period (31 days) was recorded from 23 May to 21 June.

In 1992, the flooding period of the forest was shorter and started later than in 1991. Forty-four days of flooding were recorded. Only 5 high water peak floods over 2.40 m at Saut Dalles were observed from 17 February to 31 May. Four peaks lasted only for very short periods (3 to 9 days). The longest period of flooding (21 days) lasted from 14 April to 4 May.

Mean annual rainfall (1956–1976) in the Sinnamary basin was 2777 mm (Ecerex, 1983) (Fig. 4).

Day values of percent water saturation in oxygen (at 25 °C) range from 67% to 95% in the main channel, 76% to 93% in creeks, and from 50% to 78% in the inundated forest (Richard, 1992). At night, percent saturation droped to 22% in the inundated forest while it remained at higher levels in the main channel.

Water temperatures at surface ranged from 24.3 °C (in January) to 26.8 °C (in November) during the day, both in the main channel and the inundated forest or in the channels within it (Richard, 1992). Creeks always had lower temperatures (23.3 °C to 24.2 °C). Temperature droped at night and might reach 23.5 °C in the early morning (November).

The Sinnamary river has low iron and silica

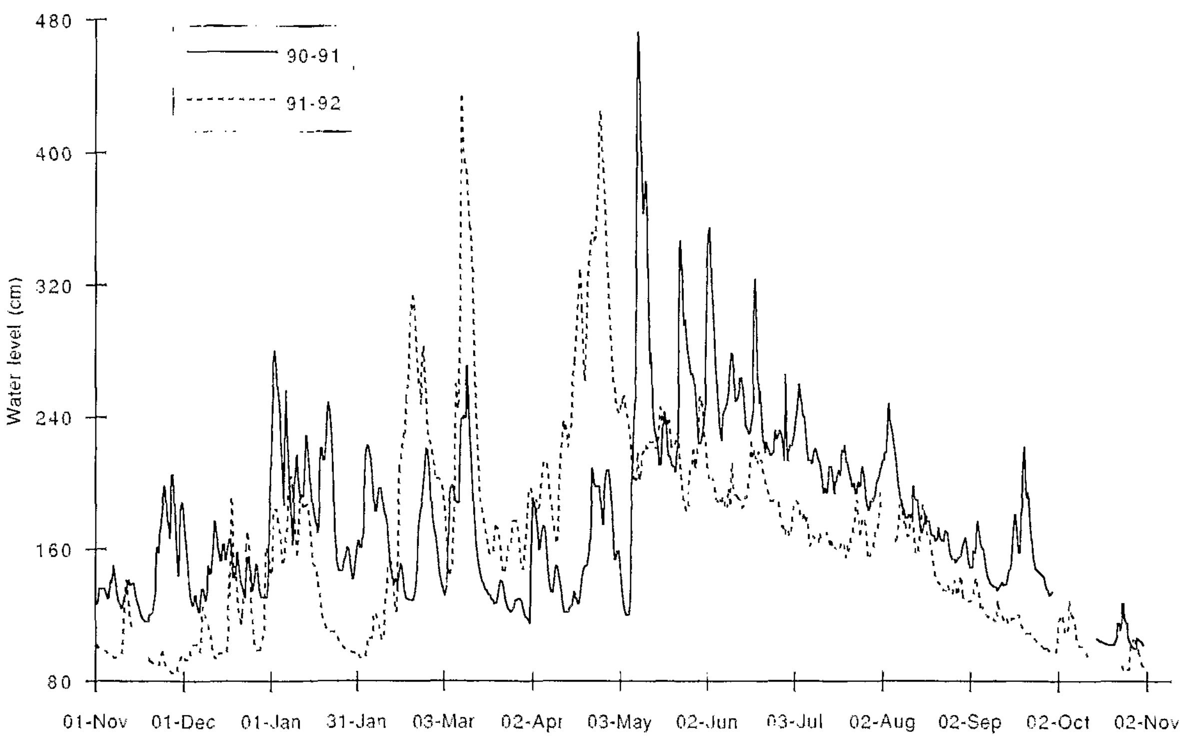


Fig. 3. Water level at Saut Dalles from November 1990 through November 1992.

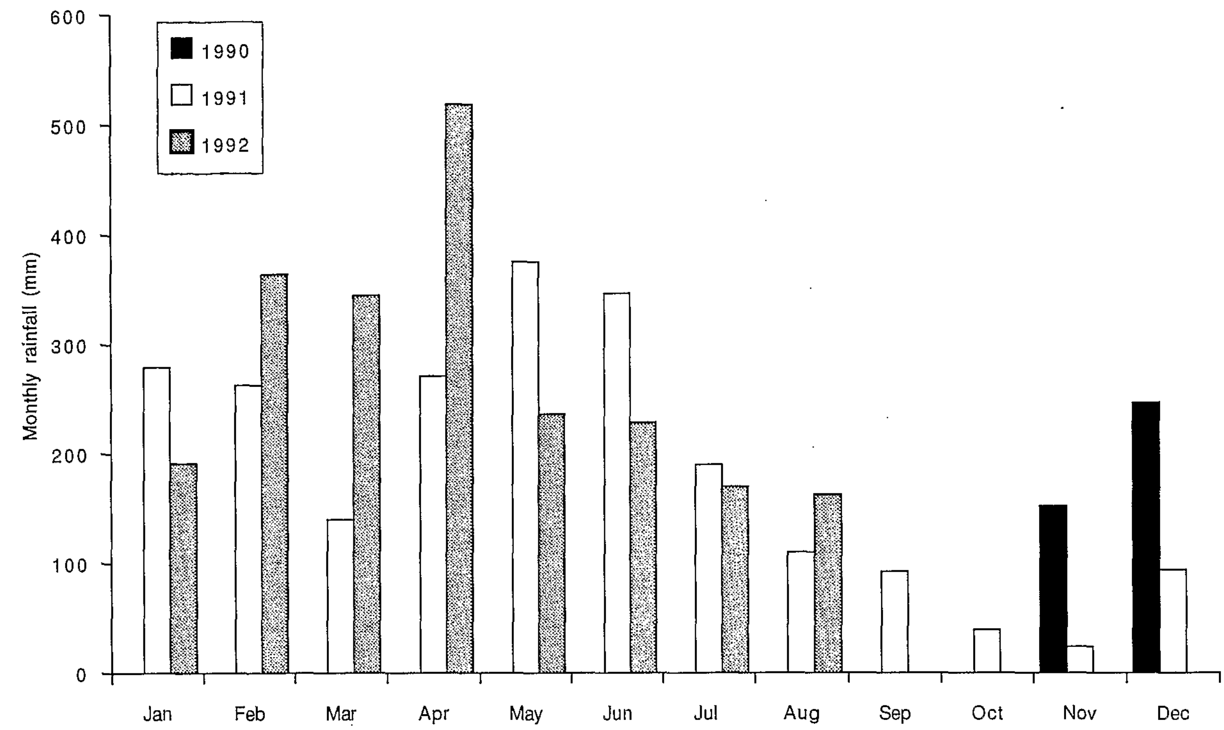


Fig. 4. Monthly rainfall in the upper Sinnamary basin upstream of Saut Dalles from November 1990 through August 1992.

content (Humbel, 1989; Richard, 1992), and the waters were close to 'clear' (Sioli, 1984). The mean hydrochemical characteristics (Humbel, 1989) were: 10 mg l^{-1} suspended matter, 4 mg l^{-1} silica, 0.5 mg l^{-1} iron, 7 mg l^{-1} Cl^{-1}. Richard (1992) found similar values for these parameters both in the main channel and in the inundated forest. She indicated also values for other parameters: pH ranges from 5.3 to 5.7, conductivity from 14.9 μS to 26.6 μS, ammonia from 6.6 μatg l^{-1} to 66.6 μatg l^{-1}, nitrite from 0 to 0.34 μatg l^{-1}, nitrate from 0 to 22.68 μatg l^{-1}, phosphates from 0 to 0.98 μatg l^{-1} and sulfate from 0.37 mg l^{-1} to 2.67 mg l^{-1}. Values recorded in creeks were always lower than in the main channel.

The flora

Forests associated with streams and rivers occupy up to 20% of the French Guianan forest vegetation (Table 2). According to de Granville (1979) (after Schnell, 1965), four forests types are associated with streams and rivers (Fig. 5):

– The low elevation upland moist forests are 'terra firme' groupings well developed on the concave margins of the rivers where they are influenced by erosion. Their border is an arborescent assemblage directly influenced by the river but not flooded by it (Oldeman, 1972). It is a high species richness riverine ecotone with forest trees and heliophilic herbs and vines ordinarily found in the canopy (Table 3).

– The permanent swamp forests vary greatly in surface, from very restricted areas to large extents. They are characterised by a constant wet layer in the underlying sediment. The understory is particularly rich in monocotyledons (Table 4, A).

– The flooded forests grow on the riparian flats, regularly submerged during the rainy season (from January to June). They are well developed on the convex margins of the rivers. Understory species,

Table 2. Species richness of the riverine flora of the upper Sinnamary compared to that of the whole French Guiana. Notes: Open formations include only vascular plants. Forest includes also bryophytes and hepatics. Figure for total number of species for French Guiana is only for the same vegetation types and not the whole flora. Species numbers do not add up because many species are shared by more than one type of vegetation.

	Whole French Guiana (1)	Whole river (2)	Mid and upper river (3)	(3)/(1) %
Open formations	357	–	29	8
Margins	286	58	25	8.7
Sand	37	–	14	38
Mud	11	–	0	0
Rock	34	–	4	12
River bed	30	–	0	0
Rocks in rapids	39	–	4	10
Swamps	31	–	1	0.03
Forest assemblages	1844	–	231	12.5
Swamp forests	203	60	45	22
Flood forests	233	38	20	8.6
Upland forest margins	1723	363	98	5.7
Swampy palm forests	100	–	–	–
Total number of samples	6658	1815	345	5.2
Total number of species	1948	809	251	12.9
Samples per species	3.4	2.24	1.37	

especially monocotyledons, are scarce and adapted to the alternation of wet and dry conditions. Pteridophytes appear to be well adapted to such conditions (Table 4, B).

– The 'pinotières' are palm swamps associated with the low muddy backwaters of most creeks. This community has a very small extent in the study area. Species richness is low (mostly dominated by *Euterpe oleracea* Martius) and is considered here as part of the permanent swamp forest.

Other typical riparian vegetal assemblages are more open formations with smaller plants (shrubs, herbs and moss):

– The backwaters and swamps with small sized vegetation, are composed of shrub and treelets associated with permanent swamp forests. They are dominated by *Triplaris weigeltiana* (Reichenbach) O. Kuntze and, along the river margins, by several species of *Inga* (*I. disticha* Bentham, *I. nobilis* Willdenow, *I. pezizifera* Bentham and mainly *I. sertulifera* De Candolle). Other common species are: *Croton cuneatus* Klotzsch, *Allamanda cathartica* Linnaeus and in the lower strata *Montrichardia arborescens* (Linnaeus) Schott and *Bonafousia siphilitica* (Linnaeus f.) Allorge. Herbaceous species are absent in this assemblage.

– The sandy margins of the active channel are important communities in the study area. The lower story is dominated by *Licania leptostachya* Bentham and *Calliandra surinamensis* Bentham. Herbaceous species are abundant (*Sauvagesia erecta* Linnaeus, *Cyperus miliifolius* Poeppig & Endlicher, *Rhynchospora cephalotes* (Linnaeus) Vahl and *Pariana campestris* Aublet but only one terrestrial fern, *Thelypteris serrata* (Cavanilles) Alston was found.

– The rocky margins have a few rupicolous species. *Turnera rupestris* Aublet is found in the lowest sections of the study area. Characteristic species of this community are: *Hypolytrum longifolium*

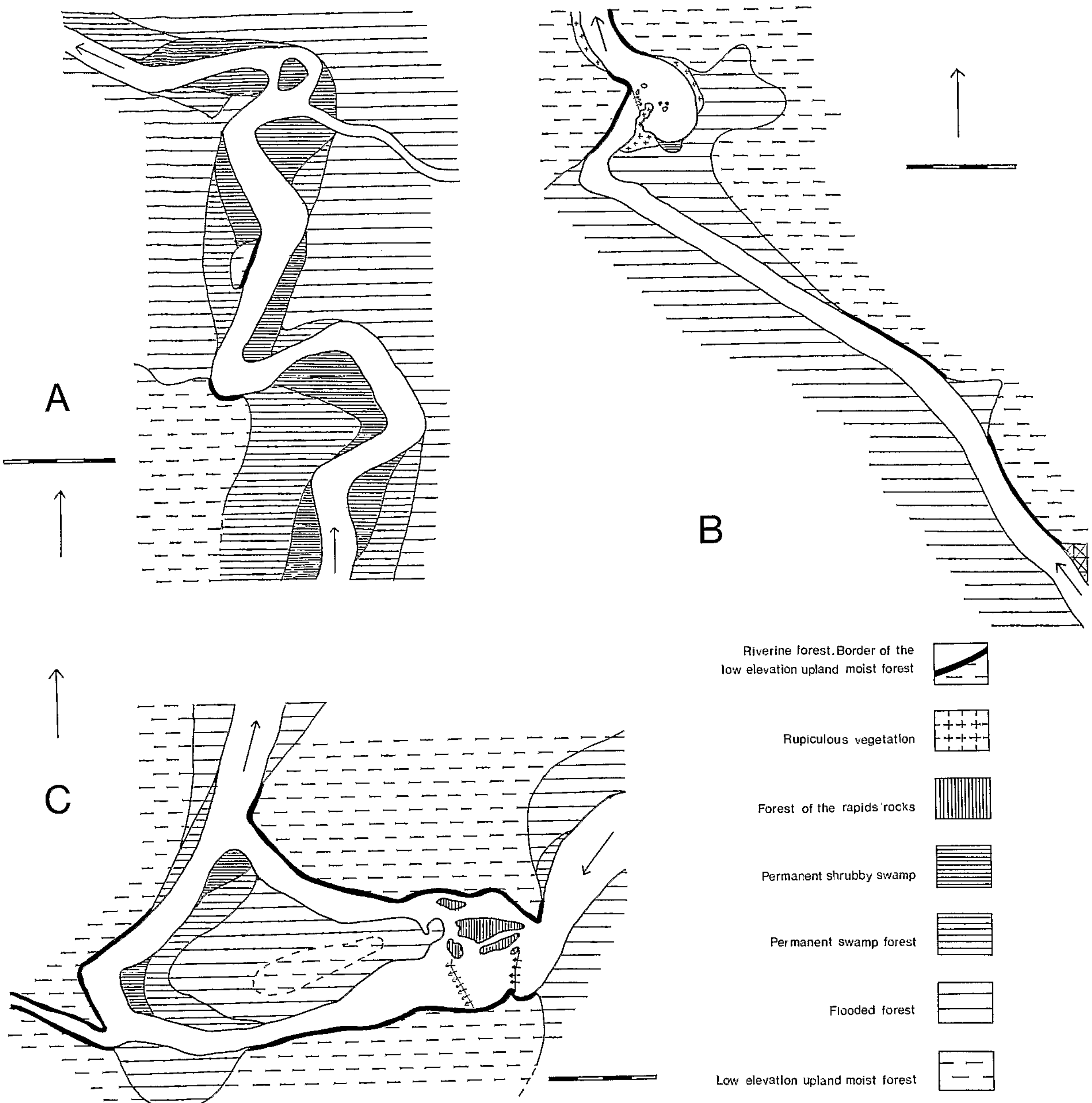


Fig. 5. Vegetation types in the three studied areas. (A) 4° 30′ N zone, (B) Saut Dalles, (C) Takari Tanté Rapids. Arrows indicate North and flow direction. Scale: each division is 40 m.

Riverine forest. Border of the low elevation upland moist forest. Rupiculous vegetation. Forest on rocks in rapids. Permanent shrubby swamp. Permanent swamp forest. Flooded forest. Low elevation upland moist forest.

(L. C. Richard) Nees (Cyperaceae) and a fern, *Trichomanes hostmannianum* (Klotzsch) Kunze.

– The rupicolous vegetation of the rapids is composed mainly of four species: *Henriettea succosa* (Aublet) De Candolle, *Calliandra surinamensis* Bentham and *Oldenlandia lancifolia* (K. Schumann) De Candolle in the sheltered zones, and *Mourera fluviatilis* Aublet along rocks in rapids.

Table 3. Main species of the riverine margins of the upland moist forest in the upper Sinnamary river.

Trees:	Epiphytes
Caesalpinaceae	Araceae
Eperua falcata Aublet	*Philodendron grandifolium* (N.J. Jacquin) Schott
E. rubiginosa Miquel	*P. squamiferum* Poeppig
Dicorynia guianensis Amshoff	Bromeliaceae
Macrolobium bifolium (Aublet) Persoon	*Pitcairnia leprieurii* Baker
Swartzia benthamiana Miquel	*Tillandsia monadelpha* (Brongniart) Urban
Vouacapoua americana Aublet	Orchidaceae
Chrysobalanaceae	*Psygmorchis pusilla* (Linnaeus) Dodson & Dressler
Hirtella bicornis Martius & Zuccarini	Epiphytic pteridophytes
H. hispidula Miquel	*Trichomanes crispum* Linnaeus
Licania canescens R. Benoist	*T. elegans* L.C. Richard
L. granvillei G.T. Prance	*Campyloneuron phyllitidis* (Linnaeus) C. Presl
L. leptotaschya Bentham	*C. repens* (Aublet) C. Presl
L. licaniiflora (Sagot) Blake	*Cochlidium linearifolium* (Desvaux) Maxon & C. Christensen
L. majuscula Sagot	*Antrophyum guyanense* Hieronymus
L. membranacea Sagot ex Lanessan	Terrestrial herbs
L. pallida Spruce ex Sagot	Cyperaceae
Paypayrola guianensis Aublet	*Mapania sylvatica* Aublet
Posoqueria latifolia (Rudge) Roemer & Schultes	Poaceae
Arecaceae	*Ichnanthus pallens* (Swartz) Munro ex Bentham
Geonoma baculifera (Poiteau) Kunth	Zingiberaceae
G. deversa (Poiteau) Kunth	*Costus congestiflorus* L.C. Richard ex Gagnepain
G. poiteauna Kunth	Terrestrial pteridophytes
Lianas	*Metaxya rostrata* (Kunth) C. Presl
Fabaceae	*Cyathea spectabilis* (Kunze) Domin
Dioclea sp.	*C. surinamensis* (Miquel) Domin
Malpighiaceae	*Selaginella falcata* (Palisot de Beauvois) Spring
Banisteriopsis lucida (L.C. Richard) Small	
Heteropterys acutifolia Adr. Jussieu	
H. macradena (De Candolle) W.R. Anderson	
H. nervosa Adr. Jussieu	

Remote sensing

The remote sensing Landsat TM images (Plate I) allowed the discrimination between riparian forest and flooded and swamp areas. The riparian forest was represented by the green pixels. Distinction is not easy within the last group. The permanent swamp forest was sometimes associated with the flooded forest (blue pixels) and sometimes with the unforested swamps (orange and white pixels).

In an area of approximately 15 km^2 at each study zone, it was possible to distinguish between the different riverine associations using the infrared bands (Table 5). The texture of the image in other areas and a finer spectral analysis of the study areas will probably allow a better discrimination in the near future.

The fish fauna

The total number of freshwater and estuarine species of fish in French Guiana is close to 600. The Sinnamary River with *ca* 130 species appears to be high in fish diversity (Table 1).

Rotenone samplings in the flooded areas

At the end of the wet season (June to early August) 49 different species were captured by roten-

Table 4. Main species of the permanent swamp forests (A) and the flooded forests (B) in the upper Sinnamary river basin.

A Permanent swamp forests

Trees
- *Symphonia globulifera* Linnaeus f.
- *Caryocar microcarpum* Ducke
- *Eschweilera pedicellata* (Richard) S. Mori
- *Lecythis corrugata* Poiteau
- *Couratari gloriosa* Sandwith
- *Bertiera guianensis* Aublet
- *Cordia nodosa* Lamark

Monocotyledons of the understory
- *Rapatea paludosa* Aublet
- *R. ulei* Pilger

Marantaceae
- *Calathea cyclophora* Baker
- *C. elliptica* (Roscoe) K. Schumann
- *C. propinqua* (Poeppig & Endlicher) Koernicke

Musaceae
- *Heliconia lourteigiae* Mello & E. Santos
- *H. spathocircinata* Aristeguieta

Zingiberaceae
- *Costus congestiflorus* L.C. Richard ex Gagnepain

Arecaceae
- *Geonoma baculifera* (Poiteau) Kunth

B Flooded forests

Trees
- *Quararibea lasiocalyx* (K. Schumann) Vischer
- *Heisteria acuminata* (Humboldt & Bonpland) Engler

Treelets
- *Psychotria racemosa* (Aublet) Raeusch
- *Leandra agrestis* (Aublet) Raddi

Monocotyledons of the understory

Arecaceae
- *Geonoma deversa* (Poiteau) Kunth

Poaceae
- *Hypolytrum longifolium* (L.C. Richard) Nees

Pteridophytes
- *Triplophyllum funestum* (Kunze) Holltum
- *Lindsaea lancea* (Linnaeus) Beddome
- *Lomagramma guianensis* (Aublet) Ching
- *Lomariopsis japurensis* (Martius) J. Smith
- *Lygodium volubile* Swartz
- *Adiantum latifolium* Lamarck
- *A. obliquum* Willdenow
- *Selaginella parkeri* (Hooker & Greville) Spring

one sampling in the flooded forest (20 to 24 at each sampling). In the channels within the flooded forest up to 54 species (28 to 35 at each sampling) were caught (Table 6). Nevertheless, the species composition was similar in the two zones (40 species in common).

The fish were similar in size at both locations. Over 40% were juveniles of larger fish found in the main stream as adults. Others were dwarf (<30 mm in standard length, *i.e.* the total length without the caudal fin) and small (<150 mm in SL) species.

Conversely, the catches were higher both in numbers and in weight in the channels than in the forest itself.

Gillnet samplings

Gillnet captures were highly variable (32 to 309 fish per capture – 11 to 39 species). Most fishes were adults.

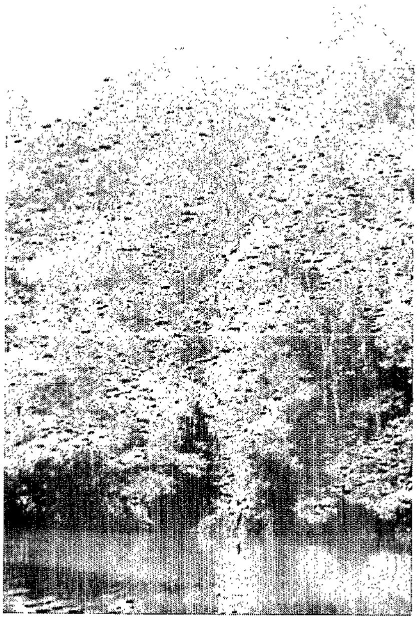
Although the number of individuals was low, the species richness was similar to that of the rotenone samplings (Table 7). Forty-one species were found in the margins of the upland forest and 52 species in the margins of the swamp zone. Because of the greater selectivity of gill-nets, larger fish were captured with this sampling method.

At the species level (Table 8), the faunal composition was different at each sampling site. A total of 92 different taxa were collected but only 15 species were common to the four zones.

Discussion

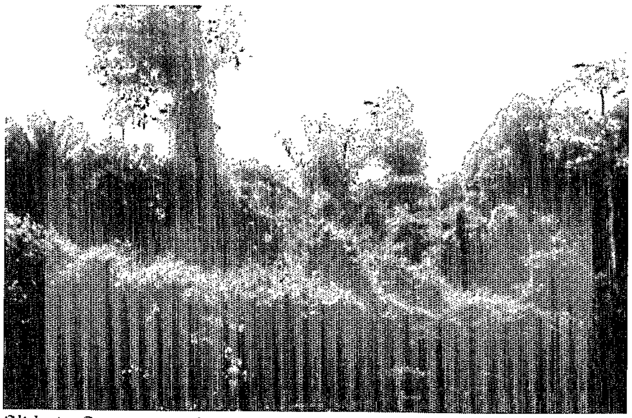
Water temperature was particularly stable in the study area. The river flood regime was intermediate between equatorial and austral regimes and directly correlated with rainfall and runoff water (Hiez & Dubreuil, 1964). Flow predictability and flood frequency were intermediate according to Poff & Ward's (1989) classification.

The input into the aquatic system of allochtonous food sources (especially insects) caught by the rising flood in the areas adjacent to the river may be important (Welcomme, 1985). But in the Sinnamary river, flood plains are scarce and of small extent in the upper reaches. In these zones, the continuous input of insects and plant litter



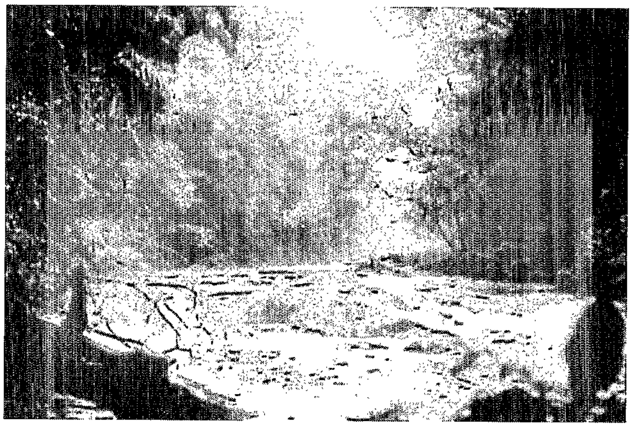
Slide 1. Upland moist forest on slope (4)30′ zone).

Slide 3. Contrast between the left and right banks. Upland moist forest (left) and flooded forest (right) (4°30′ zone).



Slide 6. Swamps and permanent swamp forest (4°30′ zone).

Slide 9. Swamps with Triplaris weigeltiana and Inga sertulifera at the base (4°30′ zone).



Side 15: Rupicoluos vegetation of the rapids.

Slide 17. Open formations and sandy floristic assemblages below the Parasol rapids.

Table 5. Surfaces and relative proportions of the three main forest types according to remote sensing calculations (C. Charron, remote sensing unit at ORSTOM Cayenne).

	Takari Tanté rapids	Saut Dalles rapids	4° 30′ section
D.E.	142	156	166
Surface	14.5	14.5	14.5
Upland	7.50	5.60	4.64
U%	70	50	50
Flooded/Swamp	0.75	2.17	0.87
F/S%	7	20	10
Swamps	2.60	3.05	3.63
S%	23	30	40
Others/water	3.85	3.63	5.36

D.E.: Distance to estuary (km).
Surface: Surface of the study section (km^2).
Upland Surface of the upland forest in the studied section.
U%: Percent surface of the upland forest.
Flooded/Swamp Surface of the flooded and swamp forest in the studied section (km^2).
F/S%: Percent surface of the flooded/swamp forest.
Swamps: Surface of the forested and unforested swamps in the studied section (km^2).
S%: Percent surface of the forested and unforested swamps.
Others/Water Surface of the other vegetation types and the river channel.

from the river banks may be of primary importance and the river continuum concept (Vannote *et al.*, 1980) provides a more appropriate template for description than the flood pulse concept of Junk *et al.* (1989).

However, the original continuum concept needs to be adapted to the differences in the riparian vegetation (Barmuta & Lake, 1982; Wiley *et al.*, 1990; Bayley & Li, 1992).

The riparian flora of the Sinnamary is still insufficiently investigated (Table 2). The number of individuals collected for each species (1.37) is much lower than that of the whole country (3.4) which demonstrates a lower sampling effort in this area. Nevertheless, close to 13% of the total number of species of plants known from French Guiana have been collected here. Indeed, three communities appear to be particularly rich: the sandy margins (38% of the total Guianan species), the flooded forests (22%), and to a less extent the rocky edges (12 %).

By contrast, the low backwater communities both forested (the 'pinotières') and unforested ('pri pris') were scarce. The low rainfall in the upper Sinnamary and its geomorphology may ex-

Table 6. Rotenone samplings in the inundated forest (swamp and flooded forest) at 4° 30′ and in the channels within the inundated forest.

	Date	N	S	W (g)	SL (mm) ± STD	$N\,m^{-2}$	$W\,m^{-2}$
Inundated forest	June 90	92	23	180	40.61 ± 27.95	0.3	0.6
	July 90	284	20	534	35.90 ± 16.52	0.7	1.3
	June 91	122	24	203	46.11 ± 38.43	0.4	0.7
	June 91	628	22	3576	37.98 ± 36.12	1.6	8.9
Channels within the inundated forest	June 90	623	28	6230	63.81 ± 34.80	3.1	31.2
	June 91	896	35	2028	48.27 ± 53.68	2.1	4.8
	Aug 91	1742	32	2959	34.06 ± 33.36	8.7	14.8
	Aug 91	1605	30	5944	25.73 ± 38.09	8.0	26.5

Date: sampling date.
N: total number of fishes.
S: species richness.
W: total weight of fishes (g).
SL ± STD: mean standard length ± standard deviation.
$N\,m^{-2}$: number of fishes per m^{-2}.
$W\,m^{-2}$: weight of fishes in g per m^{-2}.

Table 7. Gillnet samplings at the river margins. (A) Riverine margins of the low elevation upland moist forest. (B) Riverine margins of the swamp zones (both forests and shrubs).

Sampling date	Effort	N	S	W	SL ± STD	CPUE N 100 m^{-2}	CPUE W 100 m^{-2}
(A)							
Nov 89	2475	238	24	19456.00	134.86 ± 58.47	10	778.24
July 90	990	309	39	7025.00	97.10 ± 33.77	31	702.50
May 92	625	213	12	40611.50	145.00 ± 75.97	34	6497.84
(B)							
Nov 89	990	109	29	37105.00	184.60 ± 127.92	11	3710.50
June 90	1980	80	26	1803.00	106.05 ± 43.94	4	90.15
Dec 90	1980	296	28	31449.00	152.52 ± 93.99	15	1572.45
June 91	1485	35	11	7310.60	197.00 ± 88.57	2	489.81
Aug 91	1980	32	13	3535.00	146.00 ± 70.50	2	176.75
Nov 91	1875	215	30	50702.20	155.00 ± 93.63	11	2535.11

Date: sampling date.
Effort: fishing effort, *i.e.* total gillnet area (m^2).
N: total number of fishes captured.
S: species richness.
W: total weight of fishes (g).
SL ± STD: mean standard length of fishes ± standard deviation (mm).
CPUE: catch per unit effort:
N 100 m^{-2}: in number of fishes per 100 m^{-2}.
W 100 m^{-2}: in g per 100 m^{-2}.

plain their scarcity. These groupings are indeed well developed in the coastal areas where they are highly diversified (Champeau *et al.*, 1991).

In the permanent swamp forest, no adults of large fishes were found. In these areas, fish abundance varied from 0.31 fish m^2 to 1.6 fish m^2 and from 6 kg ha^{-1} to 89 kg ha^{-1}. The main role of these ecotones is probably to provide shelter to young and small fishes. The reproductive success of these populations will probably be very sensitive to any modification of these land/water ecotones (Schiemer & Zalewski, 1992).

The inundated forest and the channels within it shared 40 species. Besides the juveniles and the dwarf species under 30 mm, the fish fauna characteristic of the inundated forest and the channels was composed mainly of cichlids (*Aequidens guianensis, A. maronii, Nannacara anomala*), the small traira (*Hoplias malabaricus*) which inhabits river stretches with slow currents and low oxygen levels, *Moenkhausia oligolepis* which is very abundant in small creeks and *Hypopomus beebei*, a bottom living gymnotiform. An intermediate fauna of species from the main channel: *Leporinus friderici, L. granti, Hemiodopsis quadrimaculatus, Chilodus zunevei, Poptella orbicularis* and *Bryconops sp. aff. caudomaculatus* was also found in the channels within the inundated forest. All these species were rather ubiquitous and widespread throughout the river basin.

The fish fauna associated with the riparian ecotones of the river margins was rich and diversified. The stomach contents of the fish contained large amounts of terrestrial insects, mostly ants (Horeau, comm. pers.). These ecotones were probably of major importance in providing a diversified food source for fish.

The upland forest and the flooded forest margins had 33 fish species in common. This fauna was composed of large fish (such as *Myleus ternetzi* and the giant traira *Hoplias aimara*) and some fish associated with rocky substrates (*Deuterodon* sp.) and fast currents (*Acestrorhynchus falcatus, A. microlepis, Triportheus rotundatus, Pimelodus* *ornatus* and *Doras carinatus*). The river margin of the upland moist forest appeared to be richer in large granivorous species such as *Myleus ternetzi*. The flooded zone's margins were richer in small

Table 8. Total number of fish captured in the river margins of the upland forest (Up) in the margins of the swamp zones (Sz) and in the channels within the inundated forest (Ch) and in the inundated forest itself (If).

	Up	Sz	Ch	If		Up	Sz	Ch	If
Acestrorhynchus falcatus	18	23	3	2	*Hypostomus plecostomus*	4	23	0	0
Acestrorhynchus microlepis	75	184	0	0	*Lasiancistrus sp.*	0	2	0	0
Acestrorhynchus sp.	1	14	2	5	*Leporinus despaxi*	5	17	8	1
Aequidens maronii	0	1	16	5	*Leporinus fasciatus*	1	1	0	0
Aequidens sp.	0	1	0	0	*Leporinus friderici*	13	10	23	0
Aequidens sp. *aff. guianensis*	2	4	184	100	*Leporinus granti*	3	13	48	2
Ancistrus hoplogenys	0	0	18	0	*Leporinus* sp.	5	2	3	0
Ancistrus sp.	0	2	0	0	*Lithoxus* sp.	2	0	1	0
Anostomidae sp.	0	0	1	16	*Loricariidae* spp.	3	2	0	0
Anostomus brevior	0	6	22	2	*Moenkhausia barbouri*	0	1	0	0
Apistogramma sp.	0	0	0	1	*Moenkhausia collettii*	0	0	217	64
Astyanax sp. 1	2	9	20	8	*Moenkhausia comma*	3	0	10	1
Astyanax sp. 2 *aff. polylepis*	0	0	27	5	*Moenkhausia georgiae*	0	1	0	0
Auchenipterus nuchalis	18	23	0	0	*Moenkhausia* n. sp. *aff. barbouri*	0	0	13	0
Bivibranchia bimaculata	21	17	0	0	*Moenkhausia oligolepis*	1	9	107	126
Bryconops sp. 1 *aff. melanurus*	3	53	0	0	*Moenkhausia* sp.	0	2	0	0
Bryconops sp. 2 *aff. caudomaculatus*	153	28	28	2	*Moenkhausia* sp. *aff. surinamensis*	0	24	8	1
Bryconops sp. 3 *aff. affinis*	0	3	0	0	*Myleus rhomboidalis*	3	2	0	0
Characidae nain sp. 1	0	0	10	0	*Myleus ternetzi*	78	10	0	0
Characidae nain sp. 6	0	0	6	0	*Nannacara anomala*	0	1	38	1
Characidae nain spp.	0	0	33	0	*Parupygus savannensis*	2	2	14	0
Characidae sp.	0	0	3	0	*Phenacogaster megalostictus*	0	0	1257	26
Characidae sp. 4	0	0	0	254	*Pimelodella cristata*	11	26	16	11
Characidium sp. *gr. fasciatum*	0	0	64	11	*Pimelodella gracilis*	0	4	0	0
Chilodus zunevei	15	14	10	4	*Pimelodus ornatus*	13	4	0	0
Corydoras octocirrus	3	13	0	2	*Poptella orbicularis*	9	45	11	5
Crenicichla saxatilis	5	5	21	6	*Pristella maxillaris*	0	0	91	3
Ctenobrycon spilurus	0	0	0	42	*Pseudopimelodus albomarginatus*	0	0	1	0
Cyphocharax cyprinoides	1	0	0	0	*Pseudopimelodus raninus*	0	2	21	3
Cyphocharax helleri	0	63	32	7	*Pseudopimelodus* sp.	0	0	1	0
Cyphocharax sp.	0	0	305	132	*Pseudopimelodus* sp. 1	0	0	0	1
Cyphocharax spilurus	38	58	106	2	*Pseudopimelodus zungaro*	0	0	0	1
Deuterodon sp.	12	15	0	0	*Pseudopristella simulata*	0	0	1593	107
Doras carinatus	31	18	0	0	*Pyrrhulina filamentosa*	0	0	1	3
Eigenmannia virescens	0	4	0	0	*Rhamdia quelen*	0	0	1	1
Geophagus surinamensis	2	2	0	0	*Rivulus xiphidius*	0	0	8	2
Gymnotus carapo	0	0	56	2	*Satanoperca* sp. *aff. leucosticta*	0	1	0	0
Harttia surinamensis	6	0	0	0	*Siluriforme*	0	0	4	0
Hemiancistrus sp.	13	0	0	0	*Sternopygus macrurus*	0	0	5	1
Hemicetopsis sp.	0	0	0	1	*Synbranchus marmoratus*	0	0	3	0
Hemigrammus ocellifer	0	0	85	1	*Tatia intermedia*	0	8	136	0
Hemiodidae sp.	0	0	0	1	*Tetragonopterus chalceus*	1	0	0	0
Hemiodopsis quadrimaculatus	10	27	12	6	*Trichomycterus guianense*	0	0	2	1
Hemiodus unimaculatus	1	0	0	0	*Triportheus rotundatus*	44	10	0	2
Hoplias aimara	31	40	57	64	*Utiaritichthys* sp.	0	1	0	0
Hoplias malabaricus	1	0	25	18	Unidentified	5	0	57	44
Hypopomus beebei	0	0	23	20					

sized omnivorous species such as *Moenkhausia sp. aff. surinamensis*.

Conclusion

(1) The flora of the Sinnamary basin comprised 809 known species, 251 of which were associated with the river margins. The total plant species richness of the area, based on similar areas of other parts of French Guiana, is expected to reach 2000 species. Along the 140 km of river margins already studied, the ten plant communities encountered (both forested and non forested) offered different ecotones which are exploited by specific fish assemblages.

(2) The flooded forest comprised only 40 plant species, *i.e.* less than 10% of the total number of species occurring in this vegetation type in French Guiana. Species of fish associated with flooded forest had a lower biomass than those of the riverine margin of the upland forest.

(3) Conversely, the permanent swamp forest was highly diversified in plant species (close to 25% of the total number of species found in this formation in French Guiana). Species richness of fish in permanent swamp forest was high and comprised the very early developmental stages of several species never found elsewhere.

(4) The riverine margins of the upland moist forest possessed the highest species richness. They were associated with high fish species richness and biomass. The high fish species richness was probably related to the allochthonous food resources that are of major importance to the fish in tropical rivers. Vegetal food sources, such as leaves, fruits, and flowers, were directly exploited by fish as well as insects, especially ants, which were associated with the overhanging vegetation.

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