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IMMEDIATE DOWNSTREAM EFFECTS OF THE PETIT-SAUT DAM ON YOUNG NEOTROPICAL FISH IN A LARGE TRIBUTARY OF THE SINNAMARY RIVER (FRENCH GUIANA, SOUTH AMERICA)

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ABSTRACT

The effects of artificially low runoffs in the Sinnamary River, French Guiana, South America, on flow patterns and on richness and abundance of young fish in Venus Creek, one of its main downstream tributaries were examined. After Petit-Saut dam's gates were closed, the areas adjacent to this tributary were never once flooded for the entire duration of the rainy season. The daily maximal averages of water speed at the tributary's mouth were found to be significantly increased. Young fish sampled using light-traps were less abundant and less diverse after dam closure. Young Characiformes appeared to be the most affected by these flow disturbances. These findings enabled us to develop a conceptual model of the consequences of impoundment on young fish assemblages through the modifications of tributaries and associated floodplains hydrology. Because of flow reduction in the river during the first year of impoundment, young fish that previously had a tendency of being trapped in tributaries and flooded areas were then at risk of being flushed away. The pattern of flow release by dam operations is known to be very different from natural flow variations. The consequences for downstream tributaries will be similar to those of channelization: lack of adjacent flooding areas and higher rates of downstream water transfer. How the recovery of downstream fish assemblages will occur is discussed. © 1998 John Wiley & Sons, Ltd.

KEY WORDS: river damming; fish early life stages; neotropics; flooding areas

INTRODUCTION

River damming is referred to by Dynesius and Nilsson (1994) as 'one of the most dramatic and widespread deliberate impacts of humans on the natural environment'. The proportion of rivers presenting altered flow exceeds 20% in Africa and North America, 15% in Europe and Asia, and 5% in South America (Bravard and Petts, 1993). In 1996, the International Rivers Network estimated that more than 40000 large dams had been built in the world (International Rivers Network. 'Dam Index' http://www.irn.org/irn/pubs/damindex.html (October 1997)). Alteration of river flow regime by dams is one of the most important factors influencing the health of riverine ecosystems. It interrupts within-channel patterns and processes (Ward and Stanford, 1983) and modifies lateral interactions between channel and floodplain (Ward and Stanford, 1995).

Numerous studies have focused on the downstream effects of a dam in temperate countries (Ward and Stanford, 1995; Collier *et al.*, 1996), but studies done in the neotropics are scarce (Petr, 1978). Whatever the geographical location, most studies have still demonstrated that damming generates numerous different impacts. Reduced flow modifies the geomorphology through either channel simplification, tributary incision, or increased stability of the riverbed (Ligon *et al.*, 1995; Collier *et al.*, 1996) and retention of suspended material (Plumstead, 1990). Flow perturbations also lead to phytoplankton blooms (Mérona *et al.*, 1987) and decrease the diversity of modelized food chain (Power *et al.*, 1995). For those

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reasons, hydroelectric dams are considered to be one of the most dangerous human activities to fisheries in Amazonia (Bayley and Petrere, 1989). Dams alter carbon transfer from sources to fish (Bayley, 1989) and obstruct normal spawning migrations of important fishes for human consumption such as *Prochilodus* (Lowe-McConnell, 1987) or large pimelodid catfish (Barthem *et al.*, 1991). The completion of the Tucurui dam, one of the largest dams in South America, located on the Tocantins River immediately provoked a decrease in richness and density of fish in downstream reaches (Mérona *et al.*, 1987). In the years following, the dam brought about a drastic decrease of fishery catches (Ribeiro *et al.*, 1995). Decreases in freshwater fisheries after damming are a common pattern in numerous tropical rivers. The Murray River, in Australia, now presents 'the lowest fish yields per square kilometer of floodplain of any of the world's major rivers, although historical catches were comparable' (Walker and Thoms, 1993). Paradoxically, most studies in the tropics have focused solely on documenting the effects of flow regulation. Few of them tried to understand the causes and effects relationship, although these kinds of studies are instrumental for minimizing the negative impacts of hydrodams (Allan, 1995).

Natural floods affect fish assemblages by changing food availability and opening up floodplain habitats (Lowe-McConnell, 1987). They also create harsh conditions in which organisms are at risk of being swept away by increased water speeds (Allan, 1995). Early life stages of fish are more easily affected by flow alterations than adults (Schlosser, 1985) as they are particularly prone to displacement during flood events (Harvey, 1987). Thus, artificial downstream flow modifications may have a profound impact on fish assemblages for two main reasons: (1) they reduce the flooded areas where numerous species reproduce and where young ones find food, shelter, and protection from predation; and (2) they create hydrological conditions that early life stages of fish cannot endure.

The aims of this study were 3-fold: (1) to document the effects of artificially low runoffs in the Sinnamary River on flow patterns in one of its main downstream tributaries during Petit-Saut reservoir impoundment; (2) to examine the relationships between river flow and the richness and abundance of young fish in this downstream tributary before and after impoundment; and (3) to develop a conceptual model of the consequences of impoundment on young fish assemblages through the modifications of tributaries and associated floodplains hydrology.

STUDY AREA

The Sinnamary River

The Sinnamary River is the fifth largest river of French Guiana (Figure 1). It has a length of approximately 260 km and a mean annual discharge of 230 $m^3 \cdot s^{-1}$. Its drainage basin covers *ca.* 6565 km^2 and receives annual precipitations averaging 3000 mm (for a description of the entire river system, see Boujard, 1992 and Tito de Morais *et al.*, 1995). Its lower course, downstream from the rapids where the dam has been built, meanders through an old flat coastal plain where water levels are under the influence of tide that elevates regularly the river's fresh waters. These tidal movements cause the flow to recede into the tributaries when Sinnamary River water levels are low.

Usually, flooding is highly predictable in large rivers (Bayley, 1988). It leads to conditions that are more lentic than lotic during most of the rainy season (Bayley, 1995). On the contrary, small tropical rivers in French Guiana exhibit extreme short term variability in discharge throughout the December–July rainy season (Westby, 1988). When the discharge of a Guianese river increases, the rise in water levels in its channel produces an excess of water for the channel banks in its tributaries. As a consequence, the flow spills over and inundates the tributaries' fringing floodplains.

Petit-Saut dam

In the 1980's, Electricité de France (EDF) was licensed to build a dam (total length = 750 m, maximal height = 44 m) at Petit-Saut rapids (Figure 1). This dam was planned to have the capacity to generate 111 MW when releasing 430 $m^3 \cdot s^{-1}$ from its four generators. When the dam's gates were first closed on 5

January 1994, EDF, in agreement with French regulations, cut downstream flow to 100 $m^3 \cdot s^{-1}$ in order to fill the reservoir.

Venus Creek

The effects of flow reduction on hydrology and young fish assemblages were studied in Venus Creek (Figure 1). With a catchment area of 70 km^2, Venus Creek is one of the largest tributaries of the Sinnamary River between the dam and the estuary. Empirical observations before dam closure indicated that Venus Creek's water starts to overflow when the water level in the Sinnamary River exceeds 500 cm at Petit-Saut gauging station (D. Ponton, unpublished data).

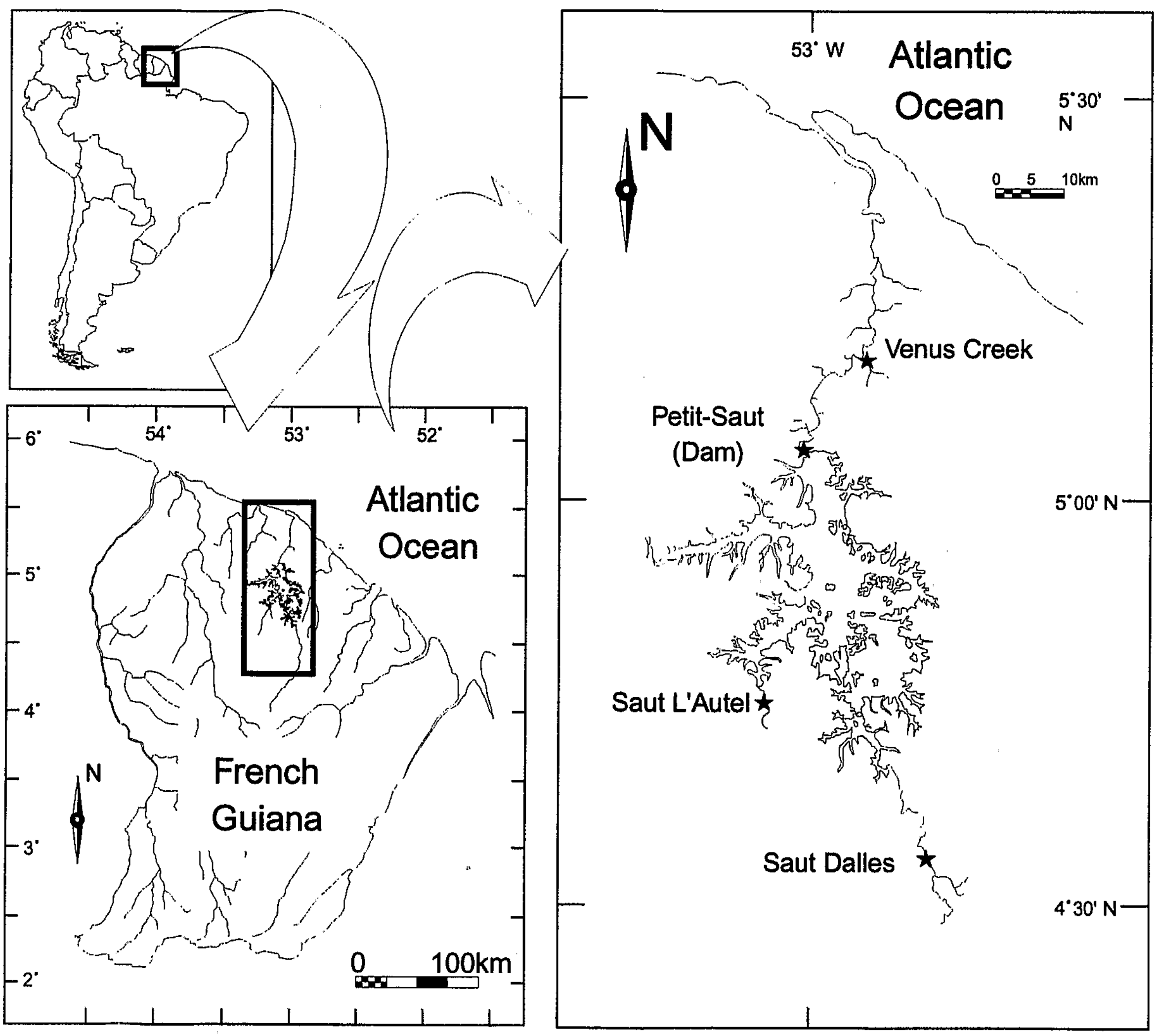

Figure 1. Map of the Sinnamary River (French Guiana, South America) from the estuary to Saut Dalles rapids and location of Venus Creek where fish sampling took place. The shape of the reservoir corresponds to the maximal water level reached in 1995. Stars indicate the location of the different gauging stations

MATERIAL AND METHODS

Hydrology

Sinnamary water levels were recorded with three ELSYDE Model CHLOE-E gauging stations that were set: (1) 300 m downstream from Petit-Saut dam; (2) upstream from Saut L'Autel rapids; and (3) upstream from Saut Dalles rapids (Figure 1). At the end of 1993, a CR2M model SAB-DBA gauging station equipped with one depth gauge and two acoustical water velocity meters (one at the surface and one at 50 cm from the bottom) was also set in Venus Creek, 200 m from its mouth.

Water levels observed at Saut l'Autel (SA_{obs} in cm), Saut Dalles (SD_{obs} in cm) and Petit-Saut gauging stations (PS_{obs} in cm) from 30 October 1990 to 5 January 1993, i.e. before dam completion, were used to establish the following relationship:

$$PS_{obs} = 1.232 * (SD_{obs} + SA_{obs}) - 104.8 \quad (F = 9578,\ df = 1154,\ p < 0.0001) \tag{1}$$

After the beginning of impoundment, this relationship was used to predict water levels at Petit-Saut gauging station that would have been observed without the dam ($PS_{w/out}$ in cm).

Similarly, water levels recorded by Petit-Saut (PS_{obs} in cm) and Venus Creek gauging stations (VC_{obs} in cm) from 15 December 1993 to 24 April 1996 were used to establish the following relationship:

$$VC_{obs} = 0.1564 * (PS_{obs}^{1.2}) + 336 \quad (F = 12691,\ df = 1432,\ p < 0.0001) \tag{2}$$

This relationship was used with $PS_{w/out}$ in order to estimate the water levels that would have been observed at Venus Creek station without the dam ($VC_{w/out}$ in cm).

A cross-sectional profile of Venus Creek near the gauging station allowed us to calculate the water section (WS_{obs} in m^2) for different water levels (VC_{obs} in cm):

$$WS_{obs} = 0.24 * VC_{obs} - 75 \quad (F = 5815,\ df = 14,\ p < 0.0001) \tag{3}$$

and thus, estimate the water section ($WS_{w/out}$) corresponding to $VC_{w/out}$

Discharge measurements with an OTT propeller currentmeter performed from March 1994 to June 1996 ($n = 12$) demonstrated that the average water velocity observed in the cross section of Venus Creek (WVA_{obs} in $cm \cdot s^{-1}$) was related to the water velocity recorded by the acoustical sensor 50 cm from the creek's bottom (WVB_{obs} in $cm \cdot s^{-1}$) by:

$$WVA_{obs} = 0.919 * WVB_{obs} - 0.8 \quad (F = 152,\ df = 10,\ p < 0.0001) \tag{4}$$

Finally, the maximal average values of water velocities that would have been observed daily in Venus Creek without the dam ($WVA_{w/out}$ in $cm \cdot s^{-1}$) were obtained by the simple arithmetic formula:

$$WVA_{w/out} = WVA_{cal} * WS_{cal}/WS_{w/out} \tag{5}$$

where WVA_{cal} is the maximal average water velocity (in $cm \cdot s^{-1}$) in Venus Creek calculated daily from Equation (4); WS_{cal}, the water section (in m^2) given by Equation (3); $WS_{w/out}$, the water section in Venus Creek without dam (in m^2) obtained from Equations (1)–(3).

As a result, it became possible to compare the distributions of daily minimal water levels and maximal water velocities recorded in Venus Creek to those that would have occurred naturally without the Petit-Saut dam.

Fish sampling

Fish sampling took place in the lower 2 km long stretch of Venus Creek before dam completion, from November 1992 to August 1993, and during the first year of impoundment, from November 1993 to August 1994 (Figure 2). At each sampling date ($n = 17$ for both periods), several modified quatrefoil light traps were set on two successive nights at *ca.* 0.5 m depth in the creek. An electronic system automatically switched on and off the light of the traps at sunset and sunrise respectively (see Ponton, 1994 for more details on the system). Sampling effort varied between ten and 20 samples at each date but the total efforts

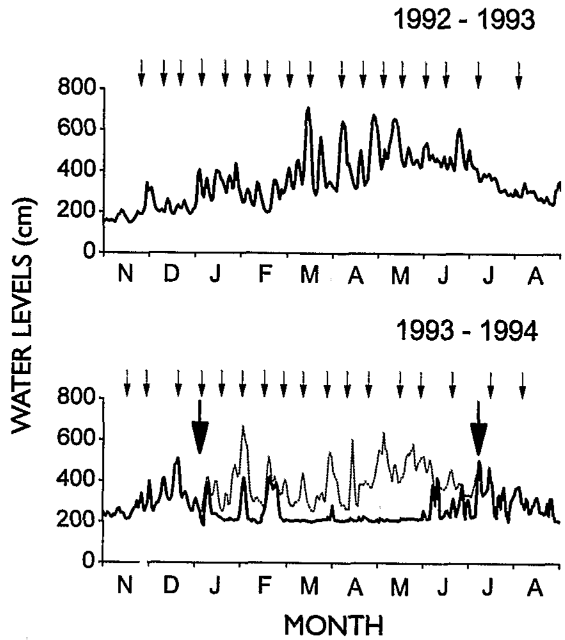

Figure 2. Water levels recorded at Petit-Saut gauging station, downstream from the dam, from November to August in 1992–1993 and in 1993–1994. Dashed line in 1993–1994 corresponds to values that would have been observed if the dam had not been built (see explanations in text). Small vertical arrows indicate fish sampling dates. The large vertical arrows correspond to the beginning and end of impoundment

were similar for each season: 284 samples in 1992–1993 and 296 in 1993–1994 (Table I). Moreover, the mean number of samples per sampling date did not differ significantly (t-test, $t = -1.073$, df $= 23$, $p = 0.655$).

After trap retrieval, fish were immediately preserved in 90% alcohol, then transferred to 70% alcohol in the laboratory. Specimens were sorted and identified using keys for adults by Géry (1977), Rojas-Beltran (1984), Kullander and Nijssen (1989), Planquette *et al.* (1996), and keys for juveniles by Ponton (unpublished). All fish were counted and measured (standard length) to the nearest 1 mm. The standard length of each fish was compared to the minimal size at first maturity of the species (Ponton and de Mérona, 1998) in order to separate young stages from adults.

Data anr 'ysis

The mean number of individuals and species per trap were calculated for each sampling date by dividing the total number of fish and the total number of species by the sampling effort (Table I). All calculations were performed separately for Characiformes and non-Characiformes and for young fish standard length (SL) < 13 mm, i.e. larvae and very young juveniles, and ≥ 13 mm, i.e. older juveniles.

Sixteen hydrological parameters of the Sinnamary River at Petit-Saut were calculated: instantaneous water level at the date of sampling, mean water level during the 5, 10 and 15 days before sampling, and number of days with water levels exceeding 300, 400, 500, 600 cm during the 5, 10 and 15 days before sampling. Only the daily minimal water level was used in order to remove tidal effect. The relationships between these parameters and the relative abundance and richness of the four groups of young fish in the Venus Creek were studied by ranking the variates and calculating the Spearman's coefficient of rank correlation. This method makes it possible to test the significance of association between two variables when 'data are known not to be bivariate normally distributed' (Sokal and Rohlf, 1981). All data analysis were performed with Systat® 6.01 for Windows (Wilkinson *et al.*, 1996).

RESULTS

Effects of impoundment on the Sinnamary River flow

Before impoundment, water levels started to increase from the end of November on, with successive flow events of short duration (Figure 2). In 1993–1994, rising water levels stopped when impoundment started on 6 January 1994 (Figure 2). During nearly all the rainy season, the river's water levels remained around 200 cm at Petit-Saut gauging station except when large discharges were released from the spillway. The first stage of impoundment stopped on 9 July 1994 and a natural flow regime, including fluctuations, resumed immediately in downstream reaches of the Sinnamary River. Nonetheless, water levels remained low.

Table I. Sampling dates, sampling effort (SE in nights), mean number of individuals, and mean number of species for Characiformes and non-Characiformes in the two sampling periods

Sampling period	Dates	SE	Mean number of individuals				Mean number of species			
			Characiformes		Non-Characiformes		Characiformes		Non-Characiformes	
			<13	≥13	<13	≥13	<13	≥13	<13	≥13
1992–1993	25–26 November	10	0.60	1.50	2.20	0	0.30	0.40	0.20	0
	9–10 December	18	0.22	1.06	1.11	0.17	0.11	0.28	0.06	0.11
	21–22 December	16	0	1.25	1.50	0.13	0	0.31	0.19	0.06
	4–5 January	16	4.94	1.19	0.31	0	0.31	0.44	0.13	0
	20–21 January	16	0.38	0.94	0.06	0	0.25	0.44	0.06	0
	3–4 February	16	0.06	0.25	0.19	0.06	0.06	0.25	0.13	0.25
	16–17 February	16	0.38	0.50	0	0	0.19	0.25	0	0
	3–4 March	16	3.19	0.06	0	0	0.31	0.06	0	0
	17–18 March	16	20.06	3.63	0.63	0.13	0.38	0.44	0.13	0.13
	7–8 April	16	1.19	1.69	0.13	0.06	0.25	0.38	0.13	0.06
	21–22 April	16	3.63	6.81	0.06	0.13	0.31	0.69	0.06	0.13
	5–6 May	16	2.50	3.81	1.88	0.19	0.31	0.75	0.06	0.06
	18–19 May	16	2.75	64.38	0	0.38	0.56	1.13	0	0.13
	2–3 June	20	0.90	30.35	0.10	0.20	0.25	0.80	0.05	0.10
	16–17 June	20	1.40	72.05	0.05	0.20	0.25	1.00	0.05	0.05
	7–8 July	20	0.25	109.30	0.05	0.10	0.15	0.85	0.05	0.10
	4–5 August	20	0.05	17.00	0	0	0.05	0.55	0	0
	Total effort	284								
1993–1994	17–18 November	17	0.12	9.41	0.88	0.06	0.12	0.41	0.12	0.06
	29–30 November	16	0	71.63	2.00	0.38	0	0.88	0.19	0.06
	21–22 December	17	3.71	24.12	0	0.24	0.35	0.71	0	0.06
	5–6 January	18	0.06	5.72	0.17	0.22	0.06	0.44	0.17	0.11
	19–20 January	17	1.24	3.94	0	0	0.35	0.41	0	0
	2–3 February	18	0	3.83	0	0	0	0.44	0	0
	17–18 February	15	0.47	5.53	0.13	0	0.20	0.73	0.07	0
	1–2 March	18	0.06	0.61	0	0	0.06	0.44	0	0
	15–16 March	18	0.06	0.61	0	0.06	0.06	0.28	0	0.06
	29–30 March	18	0.06	12.83	0.11	0.11	0.06	0.39	0.06	0.06
	13–14 April	16	0	0.69	0	0.06	0	0.38	0	0.06
	27–28 April	17	0.47	3.59	4.35	0.12	0.12	0.65	0.06	0.06
	18–19 May	19	0	1.00	0.11	0.26	0	0.37	0.11	0.16
	1–2 June	19	0.05	11.26	0.16	0.05	0.05	0.79	0.11	0.05
	22–23 June	19	0	1.63	0.05	0.05	0	0.42	0.05	0.05
	18–19 July	16	0.06	6.06	0	0	0.06	0.63	0	0
	8–9 August	18	0.06	14.28	0.06	0.28	0.06	0.72	0.06	0.17
	Total effort	296								

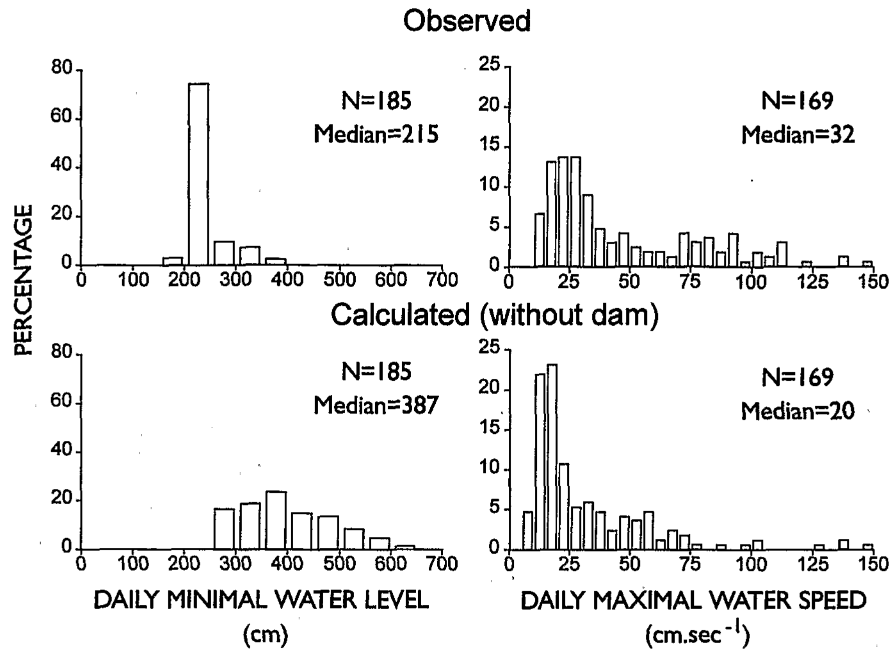

Figure 3. Observed and calculated frequency distributions of the daily minimal water levels in the Sinnamary River at Petit-Saut gauging station and the daily maximal water speeds near the entrance of Venus Creek. Calculated values are those that would have been observed without the dam (see explanations in text)

During impoundment, the distribution of water levels at Petit-Saut gauging station differed significantly from the one that theoretically would have been observed without the dam (Wilcoxon signed ranks test, $n = 185$, $Z = 11.744$, $p < 0.001$, Figure 3). The percentages of days with water levels > 300 cm and > 400 cm (13.0% and 2.2%, respectively) were significantly lower than what they would have been without the dam (83.8% and 42.2%, respectively, Fisher exact test, $p < 0.001$ for both tests). Furthermore, water levels always remained < 500 cm at Petit-Saut gauging station albeit without the dam they would have overtopped this limit over a total of 26 days. In consequence, the areas adjacent to Venus Creek were never flooded during all the 1993–1994 rainy season.

Effects of impoundment on water speeds in Venus Creek

The lower water levels in the Sinnamary River during impoundment induced a significant increase of the daily maximal values of average water speed in Venus Creek (Wilcoxon signed ranks test, $n = 169$, $Z = -11.059$, $p < 0.001$, Figure 3). More than that, the numbers of days with maximal speeds > 50 and > 100 cm·s^{-1} increased significantly from 29 to 55 and from 3 to 14, respectively (Fisher exact test, $p = 0.002$ and $p = 0.011$, respectively).

Effects of impoundment on young fish richness and abundance

The year before the dam's gates were closed, a total of 10108 fish belonging to 51 taxa, 16 families and six orders were caught (Table II). Among them, 8.1% were young fish SL < 13 mm and 59.2% were young SL ≥ 13 mm. Whatever their size, more than 80% of these young fish were Characiformes.

During impoundment, only 5774 fish of 48 taxa, 16 families and five orders were caught with a similar sampling effort (Table II). The relative abundance of young fish decreased significantly from 67.3% to 56.4% (Fisher exact test, $p < 0.001$) and from 8.1% to 4.2% of the total catches when considering only specimens SL < 13 mm (Figure 4). The percentage of Characiformes dropped significantly from 83.4% to 44.4% for young SL < 13 mm (Fisher exact test, $p < 0.001$), and decreased only from 99.5% to 98.9% for those SL ≥ 13 mm (Fisher exact test, $p = 0.002$).

Table II. List of taxa, authority, species code, and number of young fish standard length (SL) < 13 mm, SL ≥ 13 mm, caught with light-traps during 1992–1993 and 1993–1994 in Venus Creek, Sinnamary River

Order/family/genus/species	Authority	Code	1992–1993		1993–1994	
			<13	≥13	<13	≥13
Clupeiformes						
Engraulididae						
Unidentified Engraulididae		ENGR	1	3	4	–
Characiformes						
Unidentified larvae sp1		LAR1	157	–	27	–
Unidentified larvae sp2		LAR2	2	–	–	–
Unidentified larvae sp3		LAR3	16	–	3	–
Unidentified larvae sp4		LAR4	121	–	59	–
Unidentified larvae sp5		LAR5	29	–	–	–
Unidentified larvae sp6		LAR6	236	–	1	–
Unidentified larvae sp7		LAR7	9	–	–	–
Unidentified larvae sp8		LAR8	–	–	1	–
Unidentified larvae sp9		LAR9	–	–	1	–
Hemiodontidae						
Hemiodopsis quadrimaculatus	(Pellegrin, 1908)	HQUA	–	2	–	–
Parodon guianensis	Géry, 1959	PGUI	–	–	–	1
Curimatidae						
Curimatidae spp.		CUSP	1	498	–	63
Anostomidae						
Leporinus spp.		LESP	7	–	3	9
Erythrinidae						
Erythrinus erythrinus	(Schneider, 1801)	EERY	1	–	1	–
Hoplias sp.		HOPL	–	–	1	–
Lebiasinidae						
Copella carsevennensis	(Regan, 1921)	CCAR	–	–	–	5
Nannostomus beckfordi	Günther, 1872	NBEC	–	40	–	77
Pyrrhulina filamentosa	Val. in Cuv., 1846	PFIL	–	2	–	9
Characidae						
Unidentified Characidae		CHSP	–	–	–	–
Acestrorhynchus falcatus	(Bloch, 1794)	AFAL	–	8	–	–
Acestrorhynchus sp.		ACSP	–	1	–	–
Astyanax bimaculatus	(Linnaeus, 1758)	ABIM	1	233	1	3
Astyanax cf. *keithi*	Géry, Planquette and LeBail, 1996	AKEI	3	608	–	65
Bryconops spp.		BRSP	–	17	–	18
Characidium fasciadorsale		CFAS	–	27	–	8
Charax pauciradiatus	Günther, 1864	CPAU	2	–	–	–
Hemigrammus boesemani	(Géry, 1959)	HBOE	–	27		26
Hemigrammus ocellifer	(Steindachner, 1882)	HOCE	2	306	–	74
Hemigrammus schmardae	(Steindachner, 1882)	HSCH	–	100	–	2
Hemigrammus unilineatus	(Gill, 1858)	HUNI	1	9	–	5
Hyphessobrycon aff *sovichtys*	Schultz, 1944	HSOV	9	2463	5	269
Melanocharacidium sp.		MESP	–	1	–	–
Microcharacidium eleotrioides	(Géry, 1960)	MELE	–	–	1	–
Moenkhausia chrysargyrea	(Günther, 1864)	MCHR	6	37	–	12
Moenkhausia collettii	(Steindachner, 1882)	MCOL	24	874	–	297
Moenkhausia hemigrammoides	Géry, 1966	MHEM	6	218	–	716
Moenkhausia oligolepis	(Günther, 1864)	MOLI	18	155	1	11
Moenkhausia sp.		MOSP	–	1	–	1
Moenkhausia surinamensis	Géry, 1966	MSUR	–	28	–	14
Myleus spp.		MYLE	4	–	3	–
Myleus ternetzi	(Norman, 1929)	MTER	–	1	–	–
Phenacogaster aff. *megalostictus*	Eigenmann, 1909	PMEG	–	–	–	–
Poptella brevispina	Reis, 1989	PBRE	3	15	–	43

Table II. (continued)

Order/family/genus/species	Authority	Code	1992–1993		1993–1994	
			<13	≥13	<13	≥13
Pristella maxillaris	(Ulrey, 1894)	PMAX	26	236	–	717
Pseudopristella simulata	Géry, 1960	PSIM	9	53	–	536
Siluriformes						
Unidentified larvae spl		SIL1	3	–	–	–
Auchenipteridae						
Tatia intermedia	(Steindachner, 1876)	TINT	6	–	7	–
Pimelodidae						
Pseudopimelodus raninus	(Valenciennes, 1840)	PRAN	32	–	75	–
Aspredinidae						
Bunocephalus coracoideus	Cope, 1874	BCOR	–	–	1	–
Loricariidae						
Ancistrus aff. *hoplogenys*	(Günther, 1864)	AHOP	5	–	1	1
Cyprinodontiformes						
Aplocheilidae						
Rivulus agilae	Hoedeman, 1954	RAGI	–	–	–	2
Poecilidae						
Poecilia parae	(Eigenmann, 1894)	PPAR	–	–	1	–
Tomeurus gracilis	Eigenmann, 1909	TGRA	1	–	–	–
Syngnathiformes						
Syngnathidae						
Unidentified Syngnathidae		SYNG	–	1	–	–
Perciformes						
Nandidae						
Polycentrus schomburgkii	Müller and Troschel, 1848	PSCH	–	12	–	4
Perciformes						
Cichlidae						
Crenicichla saxatilis	(Linnaeus, 1758)	CSAX	–	3	–	–
Krobia guianensis	(Regan, 1905)	KGUI	–	3	2	6
Eleotridae						
Doras macrophtalmus	Puyo, 1944	DMAC	1	–	2	–
Eleotris amblyopsis	(Cope, 1870)	EAMB	67	8	42	20
Gobiidae						
Gobiidae sp.		GOBI	–	1	–	–
Unidentified		INDE	5	–	–	–
Total number of individuals			814	5990	243	3014
Total number of taxa			32	32	23	29
Total number of families			10	9	11	10
Total number of order			5	3	5	4
Relative abundance of young stages			8.1	59.2	4.2	52.2
Relative abundance of Characiformes			83.4	99.5	44.4	98.9

The dam's gates closure also gave rise to important modifications in the relative abundances of the different taxa (Figure 5). In 1992–1993, among specimens SL < 13 mm three Characiformes larvae were predominant, and among young fish SL ≥ 13 mm, *Hyphessobrycon* aff. *sovichtys* prevailed. During impoundment, three of the five most abundant taxa of young fish SL < 13 mm were Siluriformes *Pseudopimelodus raninus* and *Tatia intermedia*, or Perciformes *Eleotris amblyopsis*.

Relationship between Sinnamary River flow and young fish richness and abundance

Water level at the date of sampling (WL) and number of days with water levels > 300 mm in the 5 days before sampling (ND > 300_05D) appeared to be the only variables significantly correlated with CPUE of Characiformes SL < 13 mm (Table III). These correlations were not significant during impoundment. Under natural circumstances, CPUE of Characiformes and non-Characiformes SL ≥ 13 mm appeared strongly correlated to both mean water levels and number of days with high water levels before the sampling period. The highest Spearman's rank correlation coefficients were obtained with the number of days with water levels exceeding 400 and 500 mm. During impoundment, CPUE of both Characiformes and non-Characiformes young SL ≥ 13 mm became statistically unrelated to most of the hydrological parameters.

The relative richness of Characiformes SL < 13 mm appeared significantly correlated with instantaneous water levels (WL), mean water levels during the 5 days preceding sampling (MWL05D), and numbers of days with water levels > 500 and > 600 mm prior sampling (Table IV). Conversely, the relative richness of non-Characiformes young SL < 13 mm appeared totally independent of hydrological variables even before dam closure. Identically, the relative richness of young ≥ 13 mm presented the highest Spearman's rank correlation coefficients with the number of days with water levels exceeding 400 and 500 mm. During impoundment, the number of species SL < 13 mm or ≥ 13 mm caught per trap became independent to most of the hydrological variables.

DISCUSSION

River flow, hydrology of downstream tributaries, and young fish assemblages

During nearly all of the 1994 rainy season, low runoffs of the Sinnamary River created huge alterations of the hydrology of Venus Creek. Usually, water levels recorded at Petit-Saut gauging station exceeded bank-full depth in Venus Creek over 14–119 days from January to July (Table V). In 1993–1994, the river's water levels never exceeded 500 mm during the whole rainy season. Low water levels in the river's

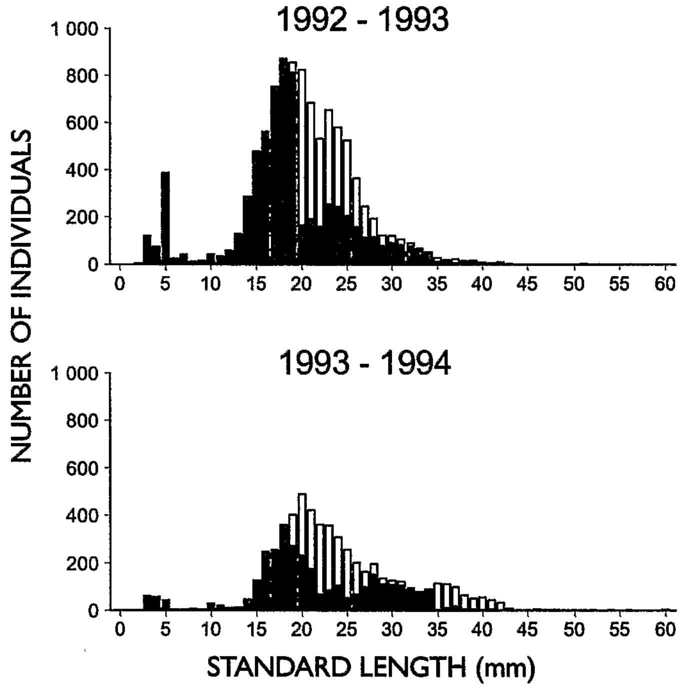

Figure 4. Size distributions of all the fish caught in Venus Creek by light-traps from November to August in the 1992–1993 and in the 1993–1994 sampling seasons. Black bars correspond to young fish standard length (SL) < 13 mm; grey bars, young fish SL ≥ 13 mm; and open bars, adults. One Syngnathidae in 1992–1993 and three *Bryconops* sp., one *Astyanax* cf. *keithi* and one *Moenkhausia chrysargyrea* had SL > 60 mm

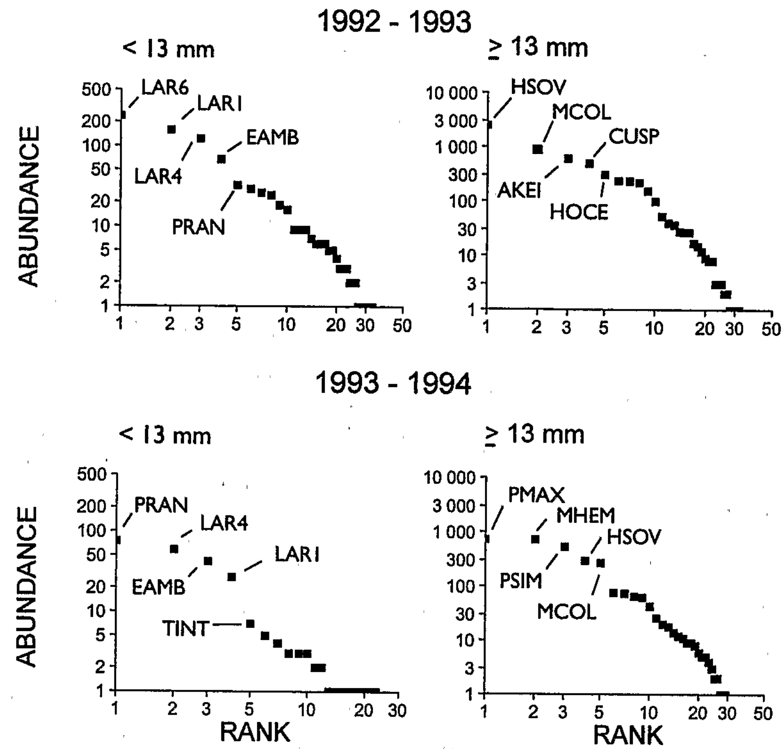

Figure 5. Ranked abundance of fish juveniles SL < 13 mm and SL ≥ 13 mm caught in Venus Creek in 1992–1993 and 1993–1994. Only the codes of the five most abundant species are presented. See Table II for the code definition

channel, regardless of precipitation, decreased Venus Creek's cross-sectional area. Under these conditions, the creek discharges, following local precipitation, were no longer slowed down. Thus, tributaries and their flooded areas evolved from retention-prone areas to regularly flushed systems (Figure 6).

Under natural conditions, Characiformes predominate among the young fish assemblages in Venus Creek during the rainy season (Table II). The overwhelming abundances of young Characiformes has also been observed when sampling with rotenone in other tributaries (Ponton and Copp, 1997). Therefore, selectivity of light traps for this group of fish (Ponton, 1994) cannot explain this result in and by itself. Abundances of young Characiformes were found to be related to the number of days of flooding in the areas bordering Venus Creek (Table IV). Most of Characiformes reproduce during the rainy season in relationship to increasing water levels and/or rainy events (Munro, 1990). By reproducing at this time of the year, these species allow their progeny to use flooded areas both as feeding grounds and shelters against predation. Moreover, most Characidae, one of the best represented group of Characiformes in the Sinnamary River, are phytophilous (Breder and Rosen, 1966; Ponton and Tito de Morais, 1994). In flooded areas, they find the submerged vegetation they need for spawning.

Flow reduction in the Sinnamary River modified drastically the young fish assemblages in Venus Creek. The total number of individuals plummeted from 10108 to 5774, and the total number of taxa decreased from 51 to 48 (Table II). The lower richness and abundance of young fish during the rainy season was mainly due to a diminution in the relative abundance of young Characiformes. The same phenomenon was also observed in ten different downstream tributaries sampled with rotenone at the end of the 1993–1994 rainy season (Ponton and Copp, 1997). Low densities of young Characiformes may originate from reproduction failure due to the lack of floods that often trigger reproduction (Lowe-McConnell, 1987). They could also originate from poor survival during early life. In fact, flow regulation is known to have profound impact on the early stages of fish independently of the latitude. In the temperate Morava River, a tributary of the Danube, Jurajda (1995) demonstrated that species richness and structure of 0+

fish assemblages depend mainly on the spawning places and potential nurseries available. In this river, channelization and regulation have reduced spawning and nursery sites to the main channel shoreline. The strongest impact has been observed for young fish of phytophilous species. A similar case was mentioned when the completion of the Goronyo Dam in Nigeria disrupted the flood pattern of the Sokoto-Rima

Table III. Spearman's (r_s) coefficient of rank correlation and significance between the relative number (mean number of individuals per trap) of Characiformes and non-Characiformes young fish SL<13 mm and ≥13 mm caught in Venus Creek and hydrological variables. With WL, water level at the date of sampling; MWL05D, MWL10D and MWL15D, mean of the water levels in the 5, 10, and 15 days before sampling, respectively; ND>300_05D, ND>300_10D, ND>300_15D, number of days with water levels>300 cm in the 5, 10, and 15 days before sampling, respectively; ND>400_05D, ND>400_10D and ND>400_15D, number of days with water levels >400 cm in the 5, 10, and 15 days before sampling, respectively; ND>500_05D, ND>500_10D and ND>500_15D, number of days with water levels>500 cm in the 5, 10, and 15 days before sampling, respectively; ND>600_05D, ND>600_10D and ND>600_15D, number of days with water levels >600 cm in the 5, 10, and 15 days before sampling, respectively

	Characiformes (r_s)				Non-Characiformes (r_s)			
	1992–1993		1993–1994		1992–1993		1993–1994	
Individuals SL<13 mm								
WL	0.640	**	0.183	ns	−0.183	ns	−0.048	ns
MWL05D	0.432	ns	0.317	ns	−0.270	ns	−0.089	ns
MWL10D	0.368	ns	0.266	ns	−0.306	ns	−0.257	ns
MWL15D	0.325	ns	0.299	ns	−0.311	ns	−0.223	ns
ND>300_05D	0.491	*	0.217	ns	−0.316	ns	−0.197	ns
ND>300_10D	0.448	ns	0.325	ns	−0.258	ns	−0.364	ns
ND>300_15D	0.385	ns	0.358	ns	−0.257	ns	−0.291	ns
ND>400_05D	0.370	ns	0.431	ns	−0.124	ns	−0.385	ns
ND>400_10D	0.286	ns	0.220	ns	−0.153	ns	−0.485	*
ND>400_15D	0.321	ns	0.328	ns	−0.157	ns	−0.274	ns
ND>500_05D	0.339	ns			0.018	ns		
ND>500_10D	0.405	ns			−0.031	ns		
ND>500_15D	0.464	ns			−0.118	ns		
ND>600_05D	0.455	ns			0.103	ns		
ND>600_10D	0.455	ns			0.103	ns		
ND>600_15D	0.455	ns			−0.034	ns		
Individuals SL≥13 mm								
WL	0.569	*	0.648	**	0.475	ns	0.024	ns
MWL05D	0.588	*	0.484	*	0.583	*	0.066	ns
MWL10D	0.659	**	0.373	ns	0.654	**	−0.056	ns
MWL15D	0.689	**	0.351	ns	0.664	**	−0.041	ns
ND>300_05D	0.514	*	0.380	ns	0.440	ns	0.200	ns
ND>300_10D	0.619	**	0.269	ns	0.608	**	0.011	ns
ND>300_15D	0.661	**	0.275	ns	0.605	*	−0.036	ns
ND>400_05D	0.806	**	0.346	ns	0.775	**	−0.013	ns
ND>400_10D	0.746	**	0.001	ns	0.765	**	−0.232	ns
ND>400_15D	0.783	**	0.045	ns	0.766	**	−0.225	ns
ND>500_05D	0.468	ns			0.476	ns		
ND>500_10D	0.626	**			0.616	**		
ND>500_15D	0.760	**			0.703	**		
ND>600_05D	0.300	ns			0.505	*		
ND>600_10D	0.300	ns			0.505	*		
ND>600_15D	0.519	*			0.508	*		

ns, non significant; * $0.01 < p \leq 0.05$; ** $p \leq 0.01$, df 15.

Table IV. Spearman's (r_s) coefficient of rank correlation and significance between the relative richness (mean number of species per trap) of Characiformes and non-Characiformes young fish standard length <13 mm and ≥13 mm caught in Venus Creek and hydrological variables. Codes for hydrological variables as in Table III

	Characiformes (r_s)				Non-Characiformes (r_s)			
	1992–1993		1993–1994		1992–1993		1993–1994	
Individuals SL < 13 mm								
WL	0.540	*	0.189	ns	−0.081	ns	−0.017	ns
MWL05D	0.484	*	0.306	ns	−0.316	ns	−0.072	ns
MWL10D	0.408	ns	0.264	ns	−0.377	ns	−0.206	ns
MWL15D	0.360	ns	0.310	ns	−0.377	ns	−0.140	ns
ND > 300_05D	0.481	ns	0.202	ns	−0.248	ns	−0.124	ns
ND > 300_10D	0.419	ns	0.320	ns	−0.272	ns	−0.294	ns
ND > 300_15D	0.354	ns	0.366	ns	−0.259	ns	−0.215	ns
ND > 400_05D	0.399	ns	0.411	ns	−0.292	ns	−0.386	ns
ND > 400_10D	0.307	ns	0.203	ns	−0.258	ns	−0.485	ns
ND > 400_15D	0.319	ns	0.332	ns	−0.213	ns	−0.224	ns
ND > 500_05D	0.495	*			−0.137	ns		
ND > 500_10D	0.520	*			−0.191	ns		
ND > 500_15D	0.501	*			−0.180	ns		
ND > 600_05D	0.622	**			−0.073	ns		
ND > 600_10D	0.622	**			−0.073	ns		
ND > 600_15D	0.573	*			−0.123	ns		
Individuals SL ≥ 13 mm								
WL	0.568	*	0.623	**	0.418	ns	−0.112	ns
MWL05D	0.699	**	0.540	*	0.454	ns	−0.052	ns
MWL10D	0.731	**	0.436	ns	0.483	*	−0.100	ns
MWL15D	0.747	**	0.456	ns	0.517	*	−0.067	ns
ND > 300_05D	0.611	**	0.445	ns	0.332	ns	0.098	ns
ND > 300_10D	0.628	**	0.307	ns	0.533	*	−0.073	ns
ND > 300_15D	0.657	**	0.408	ns	0.556	*	−0.102	ns
ND > 400_05D	0.843	**	0.228	ns	0.451	ns	−0.134	ns
ND > 400_10D	0.779	**	0.145	ns	0.584	*	−0.333	ns
ND > 400_15D	0.776	**	0.259	ns	0.587	*	−0.272	ns
ND > 500_05D	0.522	*			0.425	ns		
ND > 500_10D	0.674	**			0.566	*		
ND > 500_15D	0.765	**			0.514	*		
ND > 600_05D	0.407	ns			0.386	ns		
ND > 600_10D	0.407	ns			0.386	ns		
ND > 600_15D	0.579	*			0.543	*		

ns, non significant; * $0.01 < p \leq 0.05$; ** $p \leq 0.01$, df = 15.

floodplain (Hyslop, 1988). It impeded fish reproduction and lowered the quality of feeding conditions of the young fish. If fish reproduction occurred in the Sinnamary River in 1993–1994, the young fish encountered higher than usual water speeds in tributaries. These unusual conditions may have had a great impact on the survival of some taxa. In fact, it has been demonstrated experimentally that young fish present taxon- and size-specific susceptibility to displacement during flood events (Harvey, 1987). Three of five of the most abundant taxa LS < 13 mm in 1993–1994, *Pseudopimelodus raninus*, *Eleotris amblyopsis* and *Tatia intermedia*. are bottom-dwelling species. Lower water speeds at the bottom of the tributary may protect them from entrainment.

Perspectives

Until now very few works have documented the impact of hydroelectric dams on young fish assemblages in the tropics. To our knowledge, this study is the first one of its type in South America. However, we are fully aware that our work corresponds to a unreplicated pre- versus post-experiment without a control represented by an unaltered river. Our results are largely non-statistical and therefore can only lead to new hypothesis as a perspective. Nevertheless, they give some insight to the strong relationship that links hydrological events to the richness and abundance of young fish assemblages in tributaries of Guianese rivers. Future studies should not only document any possible recovery of fish assemblages, but also advise the electricity company in order to quicken this process. Poff and Ward (1990) suggested that the capacity of an ecosystem to resist and recover from disturbance is a function of the biota's experience with natural spatio-temporal variation. Important fluctuations in flow regime are observed from year-to-year in Guianese rivers. However, the drastic flow reduction created by impoundment does not compare to natural flow variations. During the six months of impoundment, fish species experienced a six- and twenty-fold decrease in the number of days with river water levels > 300 and > 400 mm, respectively, and not a single day with water levels > 500 mm (Table V). Data collected over 12 years before dam operation show that similar disturbances do not occur naturally at that period of the year (Table V). Thus, impoundment induced disturbances (Resh *et al.*, 1988) from which fish assemblages will have to recover.

Our work documented dam-related fish recruitment, but it is difficult to assess whether any species are endangered or not. A lot of tropical fish species in the neotropics present ecological attributes such as early maturation and short generation time (Winemiller, 1989) that may grant them resilience (Lowe-McConnell, 1987). Indeed, these species have the capacity to reproduce as soon as they encounter favourable conditions. On the other hand, their short life cycles might be a disadvantage because recruitment failure during one reproductive year has few chances of being compensated the following year. As a consequence, the recovery of downstream fish populations may occur in terms of productive capacity and overall proportions of different taxonomic groups, but the assemblages composition at the species level could be quite different.

Some authors have stated that a return of natural flooding conditions, or a simulated equivalent, is the first step in a restoration process (Bayley, 1995). Empirical evidence proved that enhanced flows below a hydroelectric dam can increase diversity and abundance of riverine fish assemblages (Deslandes *et al.*, 1995). For example, the releases of the Flaming Gorge dam on the Green River, in Utah, are now empirically seasonally adjusted to roughly mimic the river's pre-dam flow pattern (Collier *et al.*, 1996). It has been demonstrated that spring peaks in this river facilitate fish spawning and protect their young fish in backwaters. However, due to the importance of rainy events in French Guiana, it is very likely that some tributaries have cut down in response to the lower water levels of the Sinnamary River (see Ligon

Table V. Number of days with water levels in the Sinnamary River at Petit-Saut exceeding 300, 400, 500 and 600 cm between 6 January and 9 July before dam operation from 1982 to 1993, calculated values without dam, and observed values during impoundment in 1994. ND > 300, number of days with water levels > 300 cm; ND > 400, number of days with water levels > 400 cm; ND > 500, number of days with water levels > 500 cm; ND > 600, number of days with water levels > 600 cm; Q1, first quartile; Q3, third quartile

	1982–1993					1994	
	Minimal	Q1	Median	Q3	Maximal	Calculated	Observed
ND > 300	58	75	107	139	179	155	24
ND > 400	29	42	61	96	145	78	4
ND > 500	14	19	31	48	119	26	0
ND > 600	5	10	14	30	90	3	0

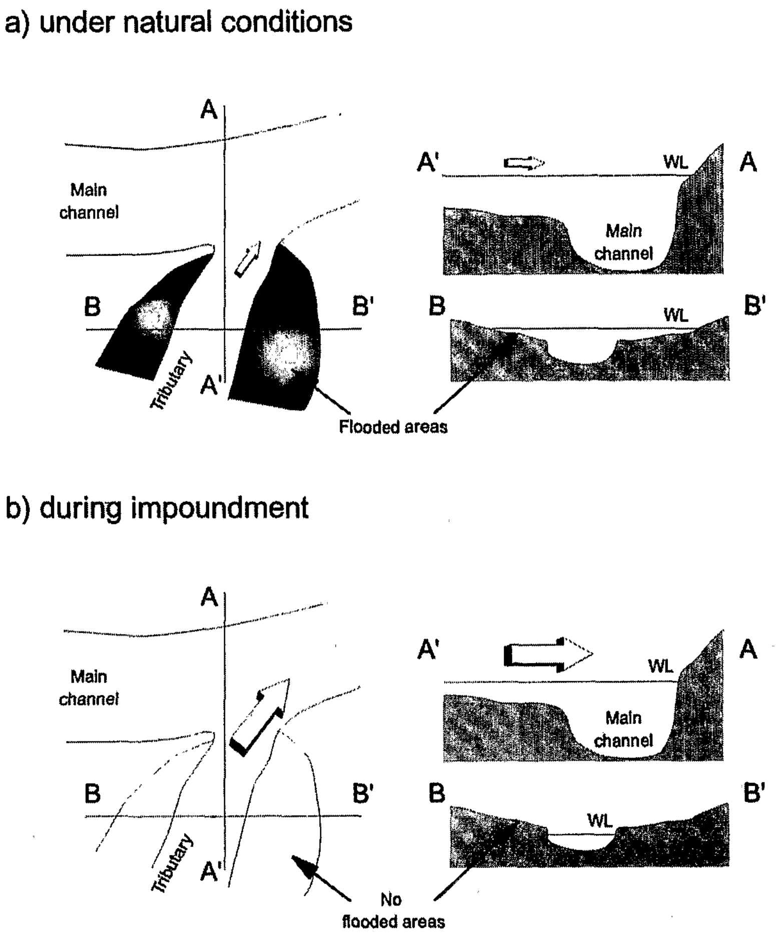

Figure 6. Schematic representation of the relationship between water levels (WL) in the main channel and tributary's hydrology. (a) Under natural conditions high water levels in the main channel induce high water levels in the tributary which spill over in adjacent areas. High water levels slow down the speed of the water coming out of the tributary. (b) During impoundment, water levels were kept low in the main channel, the tributary's fringing areas were rarely flooded and the mean speed of water coming out of the tributary was higher

et al. 1995 for a case study of this problem). In repercussion, the deeper channels of these downstream tributaries will require higher discharge in the river to spill over their banks and out onto their floodplains. Unfortunately, Petit-Saut dam operations will induce a decrease in flow intensity during the rainy season and an increase during the dry season (C. Sissakian, Electricité de France, personal communication). Regardless of the pattern of dam operation that is chosen for producing electricity, predictions are that the duration of the flooding and the expanse of the flooded area will be strongly contracted in the future. The consequences for tributaries will be similar to those of channelization, i.e. lack of adjacent flooding areas and increased rates of downstream water transfer. The aftermath of channelization is poorly documented in the tropics, but in the temperate zone it is well known that recovery time of fish assemblages in channelized streams is the longest for disturbed systems (Niemi *et al.*, 1990).

In conclusion, this study and that of Ponton and Copp (1997) have shown that young Characiformes appear very sensitive to flow-related disturbances. In general, fish larvae and juveniles are more sensitive to habitat perturbations than adults (Mathews, 1971; Schlosser, 1985; Jurajda, 1995). We thus suggest that monitoring the relative abundance and diversity of young Characiformes may be the most practical approach for documenting the possible recovery of downstream fish assemblages. In the future, the assessment of the conditions of reproduction and success of recruitment of these flow sensitive fish taxa should provide guidelines for less destructive dam operations.

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