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Movements of *Hoplias aimara* during the filling phase of the Petit-Saut dam, French Guyana

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Twenty *Hoplias aimara* were tagged intraperitoneally with radio-transmitters in the Sinnamary River, French Guyana. In November 1993, 13 tagged fish were released in an area which would be flooded by the Petit-Saut reservoir impoundment in mid-1994. Seven other tagged fish were released in January 1994, 20 km upstream of the upper limit of the reservoir. *Hoplias aimara* showed site fidelity: 75% of fish returned to their capture site before the test area was inundated. The remaining fish stayed close to the release area. Monitoring during three 24-h cycles before reservoir filling showed that *H. aimara* has a limited home range, which is less marked in unconstrained reaches during the wet season (April to August) than in constrained reaches during the dry season (September to November). In natural conditions, *H. aimara* has a wider home range in unconstrained river reaches than in constrained river reaches. After closure of the dam, in September and October 1994 (dry season, low water) more than half of the total *H. aimara* tagged in the flooded zone migrated upstream following the rise of water.

Key words: *Hoplias aimara*; dam effects; site fidelity; home range; radio-tracking.

INTRODUCTION

Freshwater radio-tracking has seldom been used in tropical areas, but Hocutt *et al.* (1994) reviewed the potential for its use in tropical waters with emphasis on Africa. Other studies in developing countries are in Hocutt (1989*a*,*b*). Mochek *et al.* (1991) carried out the only radio-tracking study in a South American freshwater. Radio-telemetry on the Sinnamary River, French Guyana began in the filling phase of the Petit-Saut dam which started in January 1994 and was expected to last 6 months.

The downstream effects are generally studied in ecological studies associated with dam building in the tropics, but the upstream effects during the filling phase have been studied rarely. Increase of fish catches in the reservoir and particularly in its upper part is generally observed but their dynamics deserve study. The present study focuses on *Hoplias aimara* (Valenciennes) which is the top predator in the Sinnamary River. It is one of the few freshwater fish species to be sought actively in Guyana by traditional fishermen and as a game fish. Knowledge of its biology and behaviour is needed. Its size allows the use of large (365-day life span) transmitters and the species is not known to perform large migrations. Thus if large movements are observed after dam impoundment they could not be

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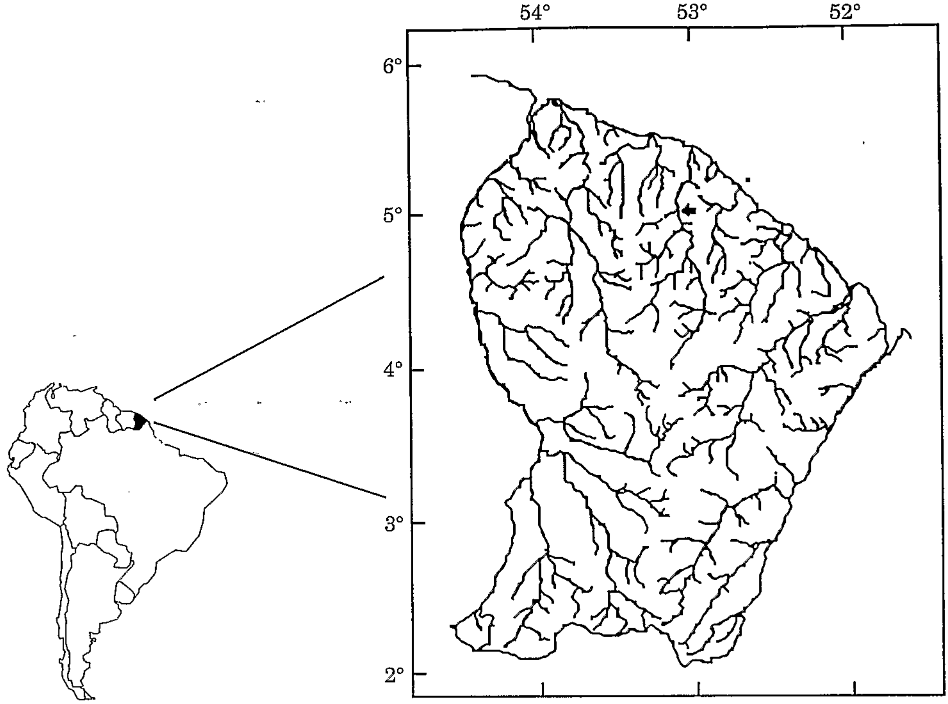

FIG. 1. Map of French Guyana indicating the Sinnamary River (arrow).

mistaken for natural migrations. The study initiated in November 1993, was planned to help answer the following questions. Does *H. aimara* display site fidelity (*sensu* Switzer, 1993)? What is its home range (*sensu* Burt, 1943) and its daily activity area under natural conditions?

Upstream or downstream movement is a reaction to adverse conditions in several fish species, both natural (Lowe-McConnell, 1964) and man-induced perturbations. Can this migration be quantified for *H. aimara* exposed to the environmental changes during the filling phase of the Petit-Saut reservoir?

MATERIAL AND METHODS

The Petit-Saut dam is located on the 250 km Sinnamary River which drains 6565 km^2 of the Guyana Shield in French Guyana, north-eastern South America (Fig. 1). The reservoir covers a surface area of 300 km^2 of moist primary tropical forest. The dry season, associated with low water levels, lasts from September to November and is followed by a short rainy season until March. March is a short period of low rain followed by a long wet season (maximum rain in May) which lasts until August.

CHOICE OF TRANSMITTERS

External attachment of transmitters may have a negative influence on the swimming behaviour of tagged fish (Baras, 1992). Internal transmitters, usually implanted in the peritoneal cavity, appear to be preferable in long-term studies (Moore *et al.*, 1990; Baras, 1992).

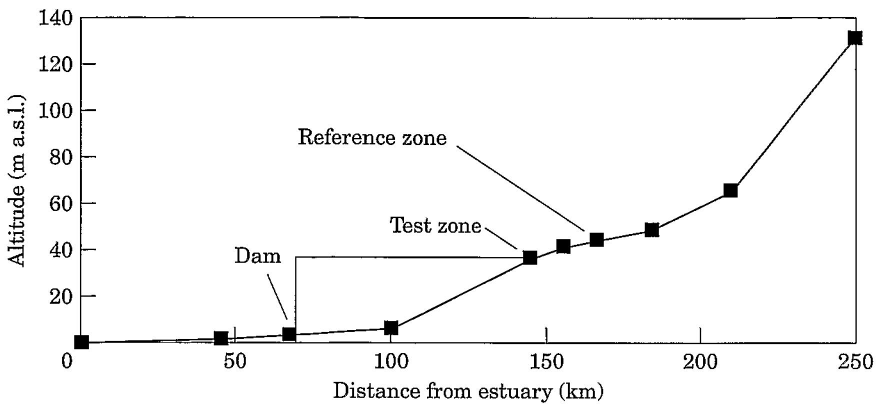

FIG. 2. Profile of the Sinnamary River indicating the distance from estuary and altitude above sea level of the study zones. Dam position and a schematic indication of the reservoir is shown.

LS6 model transmitters were used (Advanced Telemetry Systems, Inc., U.S.A.), with 365-day life span, 57–60 pulses min^{-1}, 22 g in weight and 48 MHz frequency range. Maximum reception ranges were 1500 m in the main channel and 300 m in small creeks and inundated areas (under vegetation cover).

CHOICE OF SPECIES

The planned experiment required that the same individuals were tracked under natural conditions at high and low water levels, and also after the inundation resulting from the Petit-Saut impoundment. It was necessary therefore to use 365-day life span transmitters. As the transmitters should not exceed 2% of the weight of fish (Baras, 1992), the test species had to be large (>1100 g). The giant traira *Hoplias aimara* (Valenciennes) (Erythrinidae) grows up to 1·2 m L_T and is captured alive easily using traditional traps. This species was thus retained for the study.

CHOICE OF STUDY SITES

Two zones were chosen for the experiments (Fig. 2): a reference zone upstream of the future reservoir and a test zone expected to be reached by the filling of the reservoir. The 35 m high dam at Petit-Saut is 6 m above sea level, 67·5 km from the estuary. Filling started on 6 January 1994. The raising of the water up to 32 m took 6 months. The operating level of 35 m was reached only several months later due to technical problems.

The test zone at Saut Aimara (52°56′ W, 4°40′ N), in the upper part of the reservoir 34 m above sea level, 145 km from the estuary, was selected to avoid fishing by anglers in the lower zones. Here the river flows in a succession of constrained reaches and rapids. The zone was reached by the filling flood in June 1994 (3–4 m above natural level) and is now located in the upper part of the reservoir. (The expected water rise in this area was 8–9 m, but the filling was held up by technical problems.)

The reference zone was located at 52°53′ W, 4°30′ N, 44 m above sea level, 20 km upstream of the uppermost limit of the reservoir, and so was not reached by the rising water level. Here, the river flows in unconstrained reaches. At high water levels (May and June) the riparian forest is inundated naturally.

CAPTURE AND TRACKING

Hoplias aimara were captured opportunistically using traditional wooden traps and were taken to a base station (surgical tent) where the transmitters were implanted and the fish released. Transport times were always <10 min. Fish were transported inside the traps in the bottom of the boat, covered with water. At the base station fish were transferred to a large basin containing river water and 5% phenyl-ethanol for anaesthesia.

Transmitters were implanted surgically into the abdominal cavity. A 1·5-cm opening was made 2 cm above and 2–3 cm in front of the anus. The antenna was left external and two stitches were used to close the wound. Handling and surgical procedure lasted <10 min. The fish were released 50–5600 m from the capture sites. They were placed in a small pond connected to the main river. Fish were moved back and forth in the water for 2–5 min to facilitate respiration and recovery. Though they were free to leave, fish usually stayed in the pond for *c.* 24 h.

Twenty fish were tagged, 13 in the test zone (November 1993) and seven in the reference zone (January 1994). Tracking was performed over 6 days after release. All frequencies were scanned every 500 m over a river transect. Fish were located remotely from two boats equipped with ATS Challenger Model R2100 scanning receivers and hand-held aerial loop antennae. The exact location of the fish was determined with an immersed loop antenna. Affluent streams along the river were checked regularly.

Three 24-h tracking sessions were performed also: one in the reference zone in May 1994, and two in the test zone in December 1993 and June 1994. Two reception stations equipped with adjustable loop antennae and compasses were used to record the position of the fish by biangulation every 15 min during 24 h. Mean distances travelled during 15 min intervals were compared by ANOVA. Three factors were included in the analyses: zone of tracking (test=constrained reach, reference=unconstrained reach); hydrological cycle (low water, high water level) and period of the day (dawn, 0500–0700 hours; day, 0715–1645 hours; dusk, 1700–1900 hours; and night, 1915–0445 hours). The Tukey–Kramer HSD test (Sokal & Rohlf, 1995) was used to compare the distances travelled during each period of the day and to determine which were significantly different.

Other tracking sessions were performed only to locate fish positions in January 1994, late August to early September 1994 and late October 1994. Tracking was performed from the upper basin, 80 km upstream of the reservoir, to 10 km downstream of the test zone. A χ^2 test was performed to compare the frequencies in the two zones of the fish showing movements >1 km.

Radio-tracking data were processed using the ADE-4 software available on the World Wide Web (Thioulouse *et al.*, 1995).

RESULTS

EARLY MOVEMENTS AFTER RELEASING

Only one of 20 fish died during the first 48 h after tagging. After release, the fish hid in the pond near the release area. Within 72 h, seven of 19 fish returned to their capture site (within 20 m of the precise capture location). Before the flood reached the test zone, 15 of 19 fish returned to their capture site. Capture sites were $\leq$5·6 km distance from the release area (Table I). Before the filling flood, no fish engaged in sizeable movements other than the return to capture sites.

DAILY ACTIVITY

The zone of tracking (unconstrained reaches *v.* constrained reaches), the water level (hydrological cycle at the moment of the radiotracking session) and the period of the day all had significant effects on mean distance travelled (Fig. 3; Table II). When joint effects were tested however, only water level and period of the day were significant.

Only mean distances travelled at dawn (0500–0700 hours) were significantly (α=0·05) different from other mean distances travelled (Table III).

TABLE I. Characteristics of tagged fish, distance between capture and release site and time taken to return to capture site

Zone	Ref. number and standard length (cm)	Distance (m) between capture and release site	Return time
Test	240 (75)	260	72 h
	220 (80)	600	>7 days, <2 months
	42 (70)	900	>7 days, <2 months
	340 (80)	1000	—
	280 (65)	1500	>7 days, <2 months
	380 (70)	1600	72 h
	320 (75)	1700	—
	20 (100)	2000	24 h
	80 (65)	2500	>7 days, <2 months
	100 (80)	2600	>7 days, <2 months
	260 (65)	2700	—
	120 (65)	5600	>7 days, <2 months
Reference	60 (75)	50	24 h
	300 (63)	20	24 h
	200 (73)	120	<8 months
	160 (86)	150	24 h
	140 (63)	150	24 h
	400 (74)	400	<8 months
	180 (81)	450	—

Fifteen out of 19 fishes were back to their capture zone indicating homing behaviour in *H. aimara*—indicates that fish showed no homing movement and stayed close to the release site.

BEHAVIOUR AFTER THE FILLING FLOOD

Before the filling flood, no fish engaged in movements >1 km other than the return to capture sites. After the dam impoundment, over half (four of eight detected fishes in September and seven of 11 detected fishes in October) of the fish tracked in the test zone moved upstream from 1–56 km. Five fish remained in the main river, two migrated into an affluent stream. In the reference zone only one in five detected fish moved upstream (22 km). A significantly larger number of fish moved upstream from the test zone than from the reference zone (χ^2 test: $P<0{\cdot}05$).

One fish captured by a recreational fisherman was reported, but several other missing fish may have been captured by anglers, migrated to zones upstream of the prospected area, lost tags (or transmitters malfunctioned), or been eaten by crocodiles.

DISCUSSION

Site fidelity is high in *H. aimara*. Most fish (15 of 20) returned to their capture site and none showed extended movements during several months under natural conditions. Bayley & Li (1992) distinguish between movements within a home

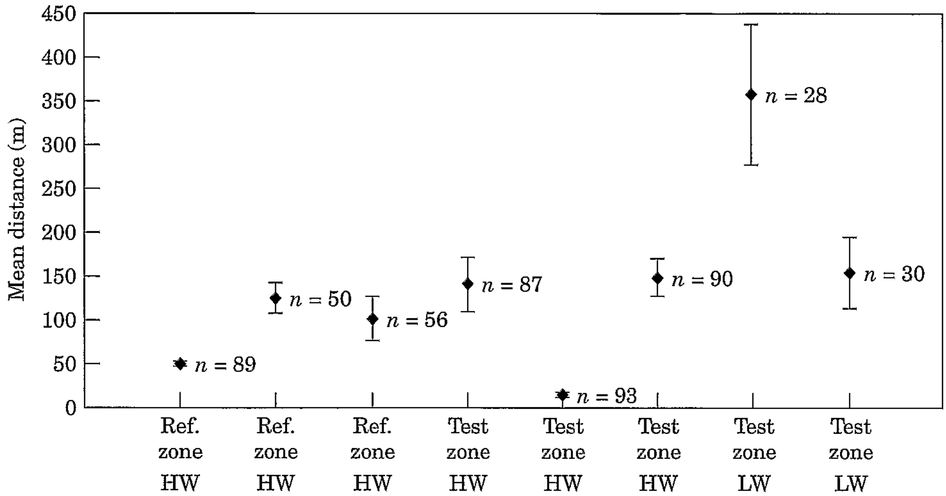

FIG. 3. Mean distance travelled in 15-min intervals during a 24-h cycle by *H. aimara* under natural conditions. Distances were measured prior to dam impoundment in two zones at two different hydrological seasons. Ref. zone HW, reference zone at high water level; Test zone HW, test zone at high water level; Test zone LW, test zone at low water level. n, is the number of values used to calculate the mean. Distance is in m ± S.E.

TABLE II. Analysis of variance for the effect of zone, water level and period of the day on mean distance travelled by fish in 15-min intervals prior to dam impoundment

Effect	d.f.	*F* ratio	*P*>*F*
Separate effects			
Zone	1	5·6510	0·017
Water level	1	32·6799	≈0
Period	3	12·3908	≈0
Joint effects			
Whole model	5	12·2231	≈0
Zone	1	0·5980	0·440
Water level	1	18·3672	≈0
Period	3	8·6979	≈0

Data are from three 24-h radio-tracking sessions. Zone corresponds to the two areas of study: reference (unconstrained reach) and test zone (constrained reach). Water level corresponds to the hydrological cycle at the moment of the radio-tracking session: high water level and low water level. Period is the time of the day (dawn, 0500–0700 hours; day, 0715–1645 hours; dusk, 1700–1900 hours; night, 1915–0445 hours). Probabilities <0·05 are considered significant.

range, typically 10^2–10^3 m, and seasonal movements of higher amplitude. In our study, under natural conditions prior to impoundment, *H. aimara* displayed home range movements. Gerking (1959) reviewed evidence that many freshwater fish species remain in restricted areas for long periods of time,

TABLE III. Values of the Tukey–Kramer test for all pairs of mean distances travelled in 15-min intervals at different periods of day

	Dawn	Dusk	Night	Day
Dawn	−103·7	54·6	96·6	106·8
Dusk	54·6	−92·1	−48·8	−38·8
Night	96·6	−48·8	−49·3	−40·7
Day	106·8	−38·8	−40·7	−57·6

Dawn, 0500–0700 hours; day, 0715–1645 hours; dusk, 1700–1900 hours; night, 1915–0445 hours. Positive values show pairs of means that are significantly different ($\alpha=0{\cdot}05$).

indicative of territoriality or restricted home ranges, which seems to be the case for *H. aimara*.

Under natural conditions, prior to dam impoundment, daily activity (mean distances travelled during 15-min intervals) differed between the test and reference zone. This indicates dualism (Eriksson, 1978) in the behaviour of *H. aimara*, i.e. behaviour is subject to variation according to time and place of observation. As suggested by Müller (1978), this dualism is related to the local physical conditions and to seasonal oscillations, both influencing the area of inundated forest in the zone. Yet hydrological cycle (high or low water level) appeared to be the main factor differentiating the extent of the fishes movements.

Hoplias aimara showed smaller mean movements during the high water than during the low water season. The latter is a period when competition for shelter and food is likely to be high (Welcomme, 1985). Conversely, at high water, more space is available, particularly in unconstrained reaches. Competition for shelter is reduced, and food is abundant due to large areas of inundated forest, particularly in the reference zone (Tito de Morais *et al.*, 1995). The food web in those tropical rivers is based on allochthonous inputs from vegetation and small animals (particularly ants) falling from the overhanging trees (Goulding, 1981; Horeau *et al.*, 1996).

As demonstrated by telemetry studies on *Tinca tinca* L. (Perrow *et al.*, 1996), shade is generally an important factor determining the distribution of some fishes. Such behaviour may also explain the difference in daily activity of *H. aimara* between low and high water levels. In the former, shade provided by the trees is limited to the margins of the river. Fish rest in restricted areas, execute some large movements of short duration and return to the previous area. When water level is high, the large areas of flooded forest allow fish to find shady places easily. Fish can explore larger areas for longer periods, but single movements between two successive fixes are shorter than when they are restricted to the main channel.

No large movements of *H. aimara* occurred before the filling of the reservoir. There was a large upstream movement as the reservoir filled. This indicates that *H. aimara* moved upstream even when the rise in water level was only 3–4 m above natural level. After the unnatural rise of water resulting from the dam impoundment, more than half of the tagged *H. aimara* migrated upstream (four of eight detected fishes in September 1994 and seven of 11 detected fishes in October 1994).

This upstream movement should increase competition for food and shelter in the upstream zones. Suitable available locations free from other *Hoplias* already settled may be scarce, and most of the moving fish did not stop in the upstream areas immediately above the reservoir. The study of the present distribution of *H. aimara* in the lake and in the affluent rivers would therefore be of interest.

Data on tropical fish behaviour under natural conditions are scarce. Freshwater telemetry studies are rare in South America. This study illustrates some of the advantages of telemetry for studying the ranging behaviour and diel activity of fish in tropical rivers. In our case, the limitations of the method, particularly the restrictions in the number and size of tracked fish, are small in regard to the difficulties of use of other methods in such South American tropical rivers, particularly in their upstream sections.

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