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Scientific Note

Evaluation of fish passage through the Igarapé Dam fish ladder (rio Paraopeba, Brazil), using marking and recapture

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Rio Paraopeba, a tributary of rio São Francisco, has a six-meter high dam, built in 1978 to divert water to the Igarapé Thermal Power Plant. In 1994, a fish ladder was built at this dam. The results of a marking and recapture program carried out along rio Paraopeba between 1997 and 2001 are described, using information from fish community studies conducted at ten sampling stations between 1994 and 1997. These investigations showed the presence of at least 91 species in the river. During four rainy seasons between 1997 and 2000, fish were caught downstream of the dam, marked with external plastic tags, and immediately released at the same site. The objective was to evaluate fish passage through the ladder, based on recapture information from artisanal and sport fishermen. A total of 3,642 specimens were marked, adding up to a biomass of approximately 1.33 tons. Twenty-six species were used, representing 28.5% of the total recorded richness (91 species). Maximum recorded tag retention time was 10 months. Total recapture rate was 4.37% in four years, reaching 5.75% in the last period (2000-2001). Of all recaptured specimens, 14.0% were caught upstream of the dam, evidencing passage through the ladder. The specimens recaptured upstream of the dam belonged to three species: piau-verdadeiro (*Leporinus obtusidens*), mandi-amarelo (*Pimelodus maculatus*) and curimatá-pioa (*Prochilodus costatus*). These species showed linear home ranges of 15.4, 81.5 and 232.0 km, respectively. Most recaptures occurred immediately downstream of the dam, one of the most intensely fished stretches of rio Paraopeba.

Desde 1978, o rio Paraopeba, um afluente do rio São Francisco, tem uma barragem de 6 metros de altura para desvio de água para a Usina Térmica de Igarapé. Em 1994, uma escada para peixes foi construída nessa barragem. Os resultados de um programa de marcação e recaptura realizado entre 1997 e 2001 são descritos, utilizando dados prévios de estudos das comunidades de peixes conduzidos em dez estações de amostragem entre 1994 e 1997. Estes estudos demonstraram a presença de pelo menos 91 espécies no rio Paraopeba. Durante quatro estações chuvosas entre 1997 e 2000, peixes foram capturados abaixo da barragem, marcados com marcas externas, e imediatamente soltos no mesmo ponto. O objetivo desse trabalho foi avaliar a passagem pela escada, com base nas recapturas informadas por pescadores artesanais e esportivos. No total foram marcados 3.642 indivíduos, atingindo aproximadamente 1,33 tonelada em biomassa. Vinte e seis espécies foram utilizadas, representando 28.5% da riqueza total registrada (91 espécies). O tempo máximo verificado de retenção da marca foi de 10 meses. A taxa de retorno total foi de 4,37% em quatro anos, atingindo 5,75% no último período (2000-2001). Do total recapturado, 14% ocorreram a montante da escada. As espécies recapturadas a montante foram o piau-verdadeiro (*Leporinus obtusidens*), mandi-amarelo (*Pimelodus maculatus*) e curimatá-pioa (*Prochilodus costatus*). Essas espécies apresentaram área de vida de 15,4, 81,5 e 232,0 km, respectivamente. O maior número de recapturas ocorreu imediatamente a jusante da barragem da UTE Igarapé, um dos locais de pesca mais intensa em todo o rio.

Key words: Rio São Francisco basin, Migration, *Prochilodus costatus*, *Leporinus obtusidens*, *Pimelodus maculatus.*

Tagging programs can provide information on the movements and migration patterns of fishes (Guy *et al*., 1996). In theory, the ideal mark should not affect mortality, growth and behavior, and must be identifiable and retained by the animal for the intended time of the study (Nielsen, 1992). In Brazil, successful marking programs to assess fish migrations were developed in rio Mogi Guaçu (Schubart, 1943 and 1954; Godoy, 1962, 1967; Nomura, 1975) and in rio São Francisco (Paiva & Bastos, 1982). Barthem & Goulding (1997) presented a compilation of knowledge on large catfish migration patterns, which, however, was based on fishery landings in several Amazonian rivers. In addition to migration patterns, marking-recapture techniques are also being used for evaluating fish passage through fish facilities (Pompeu & Martinez, 2006). Other highly specialized tagging technologies, such as telemetry, can provide more accurate results. Telemetry studies are

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quite recent in Brazil (Silva, 2004; Godinho & Kynard, 2006; Godinho *et al*., in press; Hann *et al*, 2007).

Rio Paraopeba, with an approximate length of 510 km and a drainage area of 13,642 km^2 (Cetec, 1983), is one of the most important tributaries of rio São Francisco within the state of Minas Gerais (Brazil). It has only two dams in its main stem, both located in its upper portion, and a third one is planned to be built in its lower portion. In 1978, a six-meter high dam was built on the Paraopeba to divert water to the Igarapé Thermal Power Plant, located between the municipalities of Betim and Juatuba. In 1994, a fish ladder was built to allow fish migration along the river. Because of its high species richness and the occurrence of endangered species (*Conorhynchos conirostris*), rio Paraopeba is a priority area of "high biological importance" for conservation in Minas Gerais (Drumond *et al.*, 2005).

In 1994, before the fish ladder had been completed, fish community studies were initiated and extended for up to three years after its completion. Initially (1994), three sampling surveys were conducted at eight sites along rio Paraopeba, both upstream and downstream of Igarapé Dam. In the next phase (1995-1997), ten sites distributed along the river, from its headwaters down to its lower reaches, were sampled on nine different occasions. Because these investigations showed the presence of some large-size migratory species, a fish migration study was deemed necessary.

This scientific note describes a marking and recapture program that was conducted to evaluate fish passage through the ladder.

During four consecutive rainy seasons (1997-2000), fish were collected with cast nets just downstream of the dam and kept in fish cages in the river. Groups of not more than ten individuals were brought in buckets with water to be marked. Each specimen was identified (Britski *et al.*, 1988), measured, weighed and marked with an external plastic tag. The species names were updated according to Reis *et al.* (2003) and Eschmeyer (2007). Each plastic tag, consisting of a transparent plastic tube, had a numbered message inside it, mentioning the program, the recapture information needed, and where to return it. Using a needle with a nylon line attached to it and a needle holder, the tag was attached by means of a dorsal transbody perforation near the adipose fin. Methylene blue solution was applied at the holes made by the needle. Immediately after handling, the fish was released at the same site where it had been caught.

A reward advertising program was established along the river. Posters were affixed at the most popular locations of the riverside cities and districts, requesting fishermen to report recapture data such as date, place, fish length and weight, and location in relation to the dam (upstream or downstream). The rewards were a certificate of participation and a program T-shirt.

The present study and previous experimental fishery assessments (Alves & Vono, 1997; 1999) showed the presence of at least 91 fish species in rio Paraopeba. This is a considerable number, in view of the total richness of 152 species for the entire São Francisco basin (Sato & Godinho, 2003). Twenty-six species (28.5%), which included almost all medium- and large-size species, were used in the present mark-recapture program. The specimens recaptured upstream of the dam belonged to three species: curimatá-pioa (*Prochilodus costatus*), piau-verdadeiro (*Leporinus obtusidens*) and mandi-amarelo (*Pimelodus maculatus*) (Table 1). A total of 3,642 specimens were marked, adding up to a biomass of approximately 1.33 ton.

The proportion between tag weight and body weight in air did not exceed 2.0% of fish weight, as recommended by Nielsen (1992). Mean weight of the marks did not exceed 0.53 g (± 0.05), and the lowest recorded fish weight was 40 g. Maximum recorded tag retention time was 10 months.

Total cumulative recapture rate was 4.37% in the five years of study (Fig. 1), reaching 5.75% only in the last period (2000-2001). This increase in recapture rate was probably due to intensification of the program's advertising efforts in the last two seasons. Godoy (1962), during a seven-year marking study in the Upper Paraná basin, observed annual recovery rates between 2.0 and 13.95% of marked fishes. Tagging programs are important tools to determine how successfully fish facilities allow fish passage (Clay, 1995). In rio Paraopeba river, of all the recaptured fishes, 14.0% were caught upstream of the dam, evidencing passage through the ladder. Judging from fishermen reports of higher captures upstream of the dam after 1994 (year in which the fish ladder was completed), other fish species, such as dourado (*Salminus brasiliensis*) and surubim (*Pseudoplatystoma corruscans*), may also have used the ladder. These two species had low captures, and as a result, fewer specimens were marked and no recapture occurred. Additionally, mark-recapture techniques depend on the recapture effort, which varies spatially and often greatly underestimates fish movements (Lucas & Baras, 2000). Most recaptures downstream of the dam occurred a few kilometers from it, along one of the most intensely fished stretches of the river.

The information provided by fishermen allowed only a partial evaluation of fish locations upstream and downstream of the dam (Table 1). Some reports did not include the exact location or the coordinates, so it was impossible to determine whether or not the fish used the ladder. Another problem was

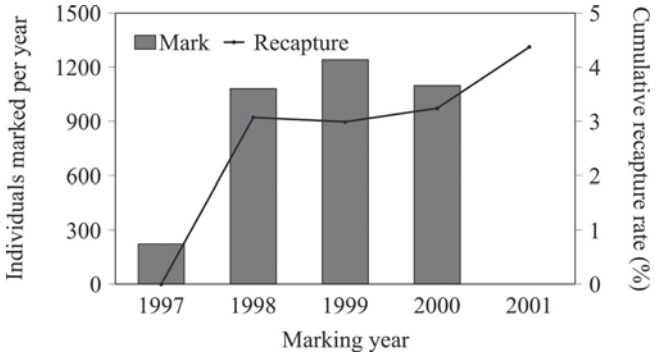

Fig. 1. Total number of fish specimens marked per year and cumulative recovery rates in rio Paraopeba, from 1997 to 2001.

underreporting due to the prohibition of commercial fishing in rio Paraopeba and also because of regulations forbidding artisanal and sport fishing during the spawning season. Thus, fishermen avoid reporting recaptures during the no-fishing period.

Assuming all marked fishes belonged to the same population of each species, linear home-range (*i.e.*, the distance between the farthest upstream and the farthest downstream recapture locations) for three species were: *L. obtusidens* – 15.4 km, *P. maculatus* – 81.5 km, and *P. costatus* – 232.0 km. These home range values are compatible with those reported in the literature, except for piau-verdadeiro (*L. obtusidens*), for which a smaller than expected linear home range value was found. This can certainly be explained by the small number of marked and recaptured specimens. For *Prochilodus argenteus* in rio São Francisco, individual linear home range varied from 26 to 127 km, based on radio-tracked specimens (Godinho & Kynard, 2006). *Prochilodus lineatus* and *P. maculatus* in a 122 km dammed stretch of rio Grande (Paraná river basin), also based on radiotelemetry data, showed lengths of 122 km and 82 km, respectively (Silva, 2004). Home range for *P. lineatus* can reach up to 1,300 km in the Upper Paraná basin (Godoy, 1972). Thus, linear home range probably depends not only on species biology, but may also be influenced by the availability of free stretches of rivers and basins. Because rio Paraopeba has no large tributaries (in length or water volume), longitudinal connectivity may play an important role in community integrity. In temperate-climate countries, longitudinal connectivity is important for the fish to spread out and re-colonize river stretches (FAO/DVWK, 2002).

The fish ladder in rio Paraopeba has a free-flowing water entrance. For this reason, when the river water level rises, a higher volume of water enters the fishway without any control. Hydraulic conditions, associated with the swimming and leaping capabilities of the fish, determine whether the fish can overcome obstacles (Larinier, 2002). Based on local observation, at the peak of the rainy season, there are high water levels in the river, resulting in an increase in water flow, velocity and turbulence inside the ladder, which probably leads to a decrease in fish ladder utilization. Such variations in water level can cause malfunctioning of fish passage facilities (Larinier, 2002; Mallen-Cooper & Stuart, 2007). Turbulence, as seen during high flows in the ladder, may discourage fish from entering or passing through it, and may also delay passage or cause injuries to the fish (Clay, 1995). More investigation is needed, and the telemetry program underway should prove this hypothesis.

Apparently, fish ladder efficiency does not depend on hydraulic features alone, but may also be influenced by water quality. This is suggested by the fact that just upstream of Igarapé Dam (~50 m), at a short distance from where the fish ladder is located, drains rio Betim, the most polluted right-bank tributary of rio Paraopeba. Rio Betim carries untreated sewage discharges from Betim and Contagem - two of the 10 largest and most industrialized cities in the state of Minas Gerais. Elimination of these pollution sources would greatly increase the chances of recovery of the fish populations to the levels recorded in the past and of restoration of the integrity of this fluvial ecosystem.

The main result of the present program is the evidence of passage through the ladder by three migratory species of rio Paraopeba (*P. costatus*, *L. obtusidens* and *P. maculatus*), which represented 90% of all marked species. With regard to the other species studied, too few specimens were marked and recaptured to allow an evaluation of the capacity of these other species to pass through the ladder and the extent to which they are affected by hydraulic and water velocity limitations.

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Table 1. Data on fish marked and recaptured in rio Paraopeba from 1997 to 2001. ND = not determined; M = mean; SD = standard deviation; Amp. = amplitude.

Species	Specimens marked	Recaptures (number of specimens)				Biometry			
						SL		BW	
		Above	Below	ND	Total	M±SD	Amp.	M±SD	Amp.
Prochilodus costatus	2,344	19	70	21	110	27.2±3.5	17.5-47.0	430.7±195.5	80-2,340
Pimelodus maculatus	620	1	25	3	29	22.0±3.0	14.5-34.5	187.2±101.4	40-1,100
Leporinus obtusidens	316	2	9	2	13	29.4±4.8	12.6-45.0	533.4±297.2	50-2,100
Hypostomus spp.	116	0	3	0	3	19.8±3.7	11.0-30.8	192.5±112.3	30-650
Salminus hilarii	49	0	1	1	2	24.8±4.3	18.5-42.2	252.9±194.0	90-1,300
Schizodon knerii	8	0	1	0	1	25.2±1.7	22.5-28.0	280.0±51.8	200-350
All other species	189	0	0	1	1				
Total	3,642	22	109	28	159	-	-	-	-

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