ECOLOGY AND CONSERVATION OF FISH IN SOUTHEASTERN BRAZILIAN RIVER BASINS SUBMITTED TO HYDROELECTRIC IMPOUNDMENTS

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INTRODUCTION

Several southeastern Brazilian river basins, including those in the state of Minas Gerais, are well suited for hydroelectric power generation. The use of such hydroelectric potential through the construction of large dams was initiated with the Três Marias dam in the upper Rio São Francisco, and resulting in the first mega Brazilian reservoir, filled in 1961, with 1,150 km^2 of surface area.

Since then, all of the main river basins of Minas Gerais have been subjected to large impoundments which have created about 6,500km^2 of flooded area, including here only reservoirs with a surface area above 1 km^2. Within the next few decades all the potential hydroelectric power of the state will have been realized, resulting in the addition of over 3,000 km^2 of new reservoirs to the present figures, equivalent to 1.6% the flooded area of the State.

With successive hydroelectric dams in operation the main river basins will have lost their riverine characteristics to approximate to lacustrine conditions. The transformation of large rivers into a succession of great artificial lakes imposes marked modifications on these ecosystems, which only recently have begun to be evaluated with regard their fish communities.

MIGRATION OF NEOTROPICAL FISH

The Neotropical freshwater fish fauna is composed of more than 2,400 species and is the most diversified and richest in the world (LOWE-McCONNELL, 1987). The majority of these species are of the

orders Characiformes and Siluriformes, and, to a lesser extent the Perciformes. Many Neotropical fish are sedentary, showing only relatively short displacements within their habitats. A significant number of them, however, migrate along the river basin (PETRERE, 1985). Migrations are usually cyclic and in shoals, and may be for various reasons (BONETTO, 1963), including reproduction and feeding.

Despite its biological importance, reproductive migration in Neotropical fish has received little attention and is consequently poorly understood. Although circumstantial evidence of migratory activity has been registered in almost all Brazilian river basins, data using mark-recapture techniques are reported only for the Rios Mogi-Guaçu (GODOY, 1975), Amazon (GODOY, 1979; WORTHMAN, 1982 in PETRERE, 1985), Parnaíba (BRAGA, 1981), São Francisco (PAIVA & BASTOS, 1982), and middle Paraná (BORGHETTI et al, 1987) and in the Promissão reservoir, Rio Tietê (BRAZIL, CESP, 1990). These studies have shown important regional variations in the migratory patterns of the local species in relation to reproduction.

In southeastern Brazil, reproductive migration (= "piracema", an indigenous word) is in the direction of the headwaters. It usually occurs in the first half of the rainy season, which extends from the middle of September to the middle of April, when the river water level and temperature are rising. The classical work carried out by GODOY (1975) between 1954 and 1963 revealed the presence of two "home grounds" for the migratory species of the Mogi-Guaçu Grande river system. The breeding areas in the Rio Mogi-Guaçu are situated between the Emas and Salto do Pinhal falls. After reproduction the fish return to their feeding grounds in the middle Rio Grande, and remain there from January to August when they again start a new migratory journey of approximately 660 km to the headwaters of the Rio Mogi-Guaçu.

From 1957-1959, PAIVA & BASTOS (1982) tagged 2,828 fish in the Rio São Francisco. Although migratory fish were recaptured, the results did not provide support for their migratory condition since they were recaptured close to the releasing site. Tagging experiments with *Piaractus mesopotamicus* at the Promissão reservoir on the Rio Tietê (BRAZIL, CESP, 1990) enabled the recapture of individuals in non-reproductive stages 110 km upstream. More complex migratory

patterns have been observed for the fish of the River Plate basin (BONETTO, 1963) and the Amazon (GOULDING, 1979; BARTHEM et al., 1991). It is also possible that more complex patterns may be found in fish from the southeastern Brazilian river basins.

THE ROLE OF THE FLOODPLAIN POOLS AND LAGOONS IN THE MAINTAINANCE OF MIGRATORY FISH DIVERSITY AND ABUNDANCE

The importance of floodplain pools and lagoons in the life history of Neotropical fish has been recognized, at least for the São Francisco river basin, since the beginning of the last century (SAINT–HILAIRE, 1817 in SATO et al., 1987). Eggs and larvae of migratory species are carried downriver and, depending on the water level, reach the floodplains. These are adequate areas for development of the alevines despite the possibilities of an early drought and the presence of high competition and or predation. Some pools and lagoons maintain their water level throughout the year, whereas others may dry out completely before being flooded again. Episodic floodings allow juvenile fish to leave the area and new batchs of eggs and larvae to reach it. The fish populations from temporary pools and lagoons tend to gradually disappear as their water volumes decrease, especially during the dry season.

Thirty-seven species of fish were present in floodplain areas of the upper Rio São Francisco above the Três Marias dam, in which Curimatidae (24.9%), Tetragonopterinae (20.2%), Anostomidae (9.6%) and Prochilodontidae (9.0%) predominated (SATO et al, 1987). This corresponds to almost half of the number of species recorded in the region of Três Marias (BRITSKI et al, 1984). Almost one third of the floodplain richness resulted from migratory species.

Various commercial migratory species, abundant elsewhere in the Rio São Francisco, were not found in these floodplains, and coincidently their capture in the Três Marias reservoir was low, suggesting that they may be severely reduced in numbers or extinct in that segment of the river (SATO et al, 1987).

In a study of the fish fauna of floodplain lagoons of the Rio Mogi-

Guaçu, GALETTI et al (1990) suggested that these environments represent true natural refuges for juveniles of, for example, *Prochilodus scrofa*. It should be considered, however, that piscivores, *Serassalmus spilopleura*, *Hoplias malabaricus*, *Salminus maxillosus* and *Salminus bilarii*, were also present, and certainly exercising strong predation pressure over *P. scrofa* juveniles.

FISH COMMUNITIES IN IMPOUNDED RIVERS

Changes in the fish communities provoked by the construction of large hydroelectric dams have been recognized since the early days of these ventures. Professional fisheries in the Rio São Francisco below the Três Marias dam are mainly sustained by *Prochilodus* spp., *Salminus brasiliensis* and *Pseudoplatystoma coruscans* — large and highly priced migratory species. Fishing in the Três Marias reservoir, on the other hand, is markedly different. Although the period allowed for fishing in the reservoir is greater than that for the river, its productivity per hectare per year is smaller. Catches of migratory species, excepting *Prochilodus* spp., are minimal and fishing relies on small sedentary species of low value. In spite of commercializing larger amounts of fish, the reservoir fishermen's annual income is lower than that of their colleagues fishing the rivers (SATO & OSÓRIO, 1985).

Negative changes can also be found for the fish community below the Três Marias dam. The most evident is the reduction in the fish population due to a decrease in water productivity and to the regulation of the river discharge. The operation of a large hydroelectric dam such as Três Marias tends to eliminate substantial changes in water level below the dam. Thus the floodplain pools and lagoons are not filled as frequently as they used to be and consequently fail to function as natural nursery areas.

Migratory fish populations locked above large dams are also affected, mainly due to a reduction in the area available for migration and to the covering of floodplain areas by the reservoir. This condition is exacerbated in rivers subject to succesive impoundments and in those close to the basin's headwaters.

THE QUESTION OF FISH LADDERS

Proposals for the construction of fish ladders at hydroelectric dams always emerge when management and conservation of the impacted fish fauna are under discussion. Over six decades ago, IHERING (1929) suggested that, under specific conditions, fish ladders could contribute to the maintainance of fish stocks in impounded rivers provided the obstacle to be surpassed does not exceed 12 m.

Large hydroelectric river impoundments constitute insurmountable barriers for fish shoals during their upriver migration. Depending on the location of the dam and the extent of the river basin above it, species less capable of supporting the barrier may, eventually, become extinct. By blocking migration the dam causes alterations in fish migration routes, but the exact nature of the changes remains unknown.

Some rivers of the American west coast have their dams equipped with mechanisms which allow migratory fish, particularly the economically important salmon, to surpass them (SCHWIEBERT, 1977). Salmonid fish ladders are efficient only because their design has been optimized due to the acquired experience for one or a small number of target species (BERNACSEK, 1984). In tropical regions, optimization of the fish ladder design would require previous selection of the species of concern (BERNACSEK, 1984) in order to achieve a national administration of the reservoir fisheries (MACHADO & ALZUGUIR, 1976). African experiences in this area are few and have been unsatisfactory (BERNACSEK, 1984).

Although they have little in common, the Brazilian experiences with fish ladders began in the 30's based on the American model. Legal requirements to build fish ladders in rivers submitted to impoundments provoked, in the past, heated discussions between Brazilian legislators and scientists. Thirty were built in the state of São Paulo alone (MENDES SOBRINHO, 1969). There are at least 3 fish ladders in the state of Minas Gerais — one in each of the Rios Tijuco, Pandeiros and Piranga.

According to GODOY (1985), the arbitrary limitation of the maximum height for fish ladders, at an evidently low value (IHERING,

1929; MENDES SOBRINHO, 1969; MACHADO & ALZUGUIR, 1976; TORLONI, 1984) has caused serious constraints to the development of Brazilian expertise in the subject.

It has been estimated that one-tenth of the migrating fish population, comprised of at least six species, pass the Emas falls through its fish ladder (GODOY, 1945). GODINHO et al. (1991) captured fish in the ladder of the Salto do Morais hydroelectric dam on the Rio Tijuco, upper Paraná basin in the state of Minas Gerais, in order to evaluate their capacity to move up the ladder steps. The ladder has 25 steps (tanks), 78.3 m long, 2.5-3,0 m wide and 10.8 m high.

Over 41 species were captured in the region of the Salto do Morais dam, at least 34 of which were present in the ladder. However, there were few individuals of these species, and only 2% of them reached the upper section of the ladder. This suggests that the Salto do Morais fish ladder is selective and obstructs the passage of all the migratory species, except *Leporellus vittatus*. The higher efficiency of the Emas fish ladder may be related to its design, since it is larger, lower, and shorter than the one at Salto do Morais. We do not believe that the use of fish ladders or any other fish passage mechanisms in impounded river basins of southeastern Brazil will be effective in significantly increasing the abundance of migratory species above the ladder.

If all hydroelectric dams indicated in governmental projects were actually constructed, then other southeastern river basins would also be transformed into a succesion of large artificial lakes. Under such conditions, migratory species will have difficulties in reproducing in the lenthic environment of the reservoirs. Even in cases where affluents may offer conditions for migration and reproduction, floodplain pools and lagoons required for population recruitment will be insufficient. Moreover, the height of modern dams imposes serious constraints to the inclusion of fish ladders due to both biological aspect and project designs. It should be mentioned, however, that due to the lack of scientific knowledge about neotropical fish transposals of hydroelectric dams, the views herein expressed should be taken with care.

THE ROLE OF THE HYDROELECTRIC COMPANY FISHERY STATIONS IN THE CONSERVATION OF THE FISH FAUNA OF THEIR RESERVOIRS

One of the most important legal measures taken to attenuate the impacts caused by hydroelectric impoundments is the Federal Decree Nº 221, February, 1967 and its regulations, which determine that the owner or concessionaire of a hydroelectric reservoir assures the conservation of the fish fauna through the creation of fishery stations. Several have been built in the states of Minas Gerais and São Paulo by their respective state electricity companies.

The conservation programs developed by those fishery stations started in the mid 70's and consisted mainly of fish repopulation of their respective river basins. In São Paulo, abouth 17 species were selected for the state program (MACHADO & ALZUGUIR, 1976). At least ten of them were non-native, including four exotics. In Minas Gerais, the proposed program for repopulation of the Furnas reservoir, Rio Grande, (BARD et al, 1978), consisted of six species, four of which were non-native, including two exotics. The lack of reliable monitoring data on our reservoir fish fauna hinders a more consistent analysis of the eventual damage provoked by introduced species. Several reservoirs in São Paulo and Minas Gerais are now colonized by *Cichla ocellaris* and *Plagioscion squamosissimus,* two non-native species included in those programs. They are carnivorous (mainly piscivores), and originally from the Amazon basin.

Cichla ocellaris is well known for its voraciousness, high value for consumption and as a sport fish. It may cause severe damage to host environments, such as lake Gatun, Panamá, where several native species were wiped out six years after its accidental introduction (ZARET, 1982). It is today one of the main species in Três Marias reservoir fishery. Data on experimental fisheries revealed an increase in 650% in the biomass of *Cichla ocellaris* from July 1985 to June 1987 (SATO & GODINHO, 1988). The 30-year history of its introduction in a northeastern Brazilian reservoir has shown that it was responsible for 15% to 53% of the local catches (FONTENELE & PEIXOTO, 1979). Significant modifications may be expected in the native fish

communities of reservoirs where *Cichla ocellaris* has been successfully established.

Plagioscion squamosissimus, introduced by the São Paulo Electricity Company (CESP), in 1968, in some reservoirs in the state of São Paulo, occupied first place in biomass during experimental fisheries performed at the Promissão reservoir in the Rio Tietê (BRAZIL, CESP/UFSCar, 1990). It was also the main species captured in experimental fisheries carried out at the Volta Grande reservoir, Rio Grande, from August, 1987 to July, 1988 (unpublished data). Data on damage caused by *P. squamosissimus* to the host environments are unavailable. Fishermen from the Porto Colombia and Marimbondo reservoirs, both in the Rio Grande, complain of the drastic reduction of *Astyanax* spp. following the introduction of *P. squamosissimus.*

Adequate programs undertaken by hydroelectric company fishery stations are, at present, one of most important measures towards fish fauna conservation in southeastern Brazil. Fortunately, today most of their programs are now devoted to the different aspects of biological conservation of the native species. Techniques on artificial propagation are being developed as part of their repopulation programs and they are being applied successfully. The results of this work along with a greater awareness concerning problems of conservation regarding fish introductions by the scientists themselves have contributed to the increasing use of native species.

More extensive limnological and icthyological monitoring programs have been established for some reservoirs, and projects are under way to extend them to others (see TORLONI, this volume). Long term monitoring programs are mandatory not only for the correct analysis and interpretation of the effects of repopulation on the host environment, but also to provide the necessary tools for the establishment of fishery regulations in our reservoirs, which are still so far empirical.

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