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FISHERIES MANAGEMENT IN BRAZILIAN RESERVOIRS:

LESSONS FROM/FOR SOUTH AMERICA

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SUMMARY

In the last decades, main actions related to fisheries management in Brazilian reservoirs (regulations, stocking, and construction of fish ladders) were, in general, not successful. Reasons for that were shortage of scientific information, limitations of financial and human resources, and absence of monitoring. Apparently these actions were based on a paradigm ("biological deserts") which revealed itself misleading. The tendency of supporting the actions according to the ongoing paradigm ("biomanipulation") seems to be promising. This paradigm incorporates a more holistic view of the fisheries (environment, fishermen and fish) and considers monitoring and feedback. Moreover, for an effective management the concept of hydrographic basins and multiple uses must be considered, recognizing biological, political, and socio-economic limitations in the decision making process.

RESUMEN

En las últimas décadas, las principales acciones tomadas en relación al manejo pesquero en embalses brasileros (control, stock y construcción de escaleras para peces) fueron, en general, ineficientes. Las razones que condujeron a esta ineficiencia pueden ser atribuídas a la escasez de información, limitación de recursos financieros y humanos, y a la falta de monitoreos. Estas razones fueron, aparentemente, basadas en un paradigma ("desierto biológico"), que luego se demostró equívoco. La tendencia de basar acciones conforme un nuevo paradigma, actualmente vigente ("biomanipulación"), se muestra promisoria. Este nuevo paradigma incorpora una visión más holística de las pesquerías (el ambiente, el pescador, el pez) y presupone monitoreo y retroalimentación. Además, para que el manejo sea efectivo, se debe considerar el concepto de cuenca hidrográfica y el de uso múltiple, reconociendo las limitaciones biológicas, políticas y socio económicas en el proceso decisivo.

Introduction

Management of natural resources is a discipline that, historically, presents spectacular mistakes. However, practitioners do not change their objectives based on past experiences (Ludwig *et al*., 1993). Apparently, those mistakes are unavoidable consequences of the contradiction between human aspirations (unlimited demand) and the capability of achieving them (limited resources), lack of information on the system to be managed, lack or inadequate monitoring, and high natural variability of resource abundance.

KEY WORDS / Fish Ladder / Fishery Control / Management / Reservoir Fishery / Stocking /

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RESUMO

Nas últimas décadas, as principais ações tomadas em relação ao manejo da pesca em reservatórios brasileiros (controle, estocagem e construção de escadas de peixe) foram, em geral, ineficientes. As razões do insucesso podem ser atribuídas à escassez de informações, limitações de recursos financeiros e humanos e, a falta de monitoramento. Estas ações foram, aparentemente, baseadas em um paradigma ("deserto biológico"), que se revelou equivocado. A tendência de pautar as ações conforme um novo paradigma, agora vigente ("biomanipulação"), revela-se promissora. Esse novo paradigma incorpora uma visão abrangente do sistema de pesca (o ambiente, o pescador e o peixe) e pressupõe monitoramento e retroalimentação. Além disso, para que o manejo seja efetivo, deve considerar o conceito de bacia hidrográfica e usos múltiplos, reconhecendo as limitações biológicas, políticas e sócio-econômicas no processo decisório.

These are among the main problems that affect management efficacy.

In the last decades, most actions taken by the Brazilian hydropower companies (hereafter named 'Sector') to manage fisheries were inefficient or even harmful to stocks. Recently, there is a tendency of abandoning several "trial and error" practices, especially those related to stocking of exotic species. Forced by law or Sector's decision (e.g. Itaipu Binacional) the main approach to manage fisheries nowadays considers surveys of basic information before any action is taken. This tendency has been reinforced in discussions held by the Sector in several thematic meetings promoted by the Environmental Coordinator Committee of the Brazilian Electric Sector (*Comitê Coordenador das Atividades de Meio Ambiente do Setor Elétrico Brasileiro - COMASE*), as part of the Seminars of Aquatic Fauna and the Brazilian Electric Sector (*Seminário Sobre Fauna Aquática e o Setor Elétrico Brasileiro*; Seminários, 1995). However, these activities are isolated and not linked to a management plan. In addition, surveys, studies and monitoring are not clearly defined and, in most cases, they are interpreted as being a similar thing. This terminological misunderstanding is not a simple semantic issue when we try to establish a strategy to mitigate impacts and protect fishery resources. Therefore, clear definitions are relevant when planning environmental actions due to their sequential character and prerequisite relations (see Agostinho and Gomes, 1997)

Management considers implementation of actions on a system attempting to optimize it according to given objectives. For fishery resources, interpretation of management has been intensely debated in the literature. Initially understood as fishery control in opposition to the belief spread in the 19th Century that fishery resources were unlimited, the definition got broader in the last decades (Huxley, 1883, cited in King, 1995). Carlander (1969) defined management as anything done in order to keep or to improve resources and their exploitation, whereas Lackey (1978) defined it as an analysis of alternative decisions and their implementations, in consonance with society aspirations in relation to uses of aquatic resources. For instance, Krueger and Decker (1993) defined management as integration of ecological, economical, political and socio-cultural information to make decisions that culminate in actions to achieve established goals in relation to fishery resources.

For large water bodies, management should be directed towards maintaining biological diversity and/or sustaining fish stocks exploited either commercially or recreationally. Then, management is an activity that essentially deals with abundance of individuals in several organizational levels of ecological systems.

Management for conservation prioritizes actions directed to maintain population demography and genetics above thresholds for spawning and for evolutionary processes needed for long term existence. In this context, removal, contamination and fragmentation of habitats, overexploitation, inbreeding and hybridization are the most relevant aspects. In spite of the focus of management for conservation on population or populations of one or some species near extinction, consideration of the framework of communities is essential, particularly of interactions among species that can lead to elimination of other elements of the fauna. Therefore, models of population viability should consider, besides population size and genetic variability, species interactions and responses of communities to environmental perturbations.

On the other hand, management for exploitation intends to grant high sustainable yield from the resource. This may be achieved by measures that attempt to promote better recruitment (improved spawning conditions and juvenile survival), to increase the biogenic capacity of the environment, to reduce natural mortality and fishery control.

Damming rivers negatively impacts biological diversity. Thus, for ethical reasons, management of reservoirs can not be based only in the increment of fishery yield. It should seriously consider protecting and maintaining diversity (Agostinho, 1994a, b). As reservoir converge areas of human activities and are strongly influenced by basin upstream, knowledge for sound management goes well beyond reservoir boundaries. Sometimes, management actions applied on critical areas located outside the reservoirs may be more effective in achieving management goals. In this paper, we will report how fishery management was conducted in Brazil. The main actions undertaken to manage fisheries and the problems related to them are specifically described. At the end, we consider, according to our view, how fishery management should be conducted in the future. This view may be important to manage fishery resources in other South American countries.

The scenario

Management of fisheries resources in Brazilian reservoirs is occasional and usually based on poor technical and scientific information. Historically (since the 1970's), management actions included fishery control and stocking, both with reduced efficacy. These actions were preceded by construction of fish ladders, built with the purpose to mitigate the impacts of the dams on fish migration. Absence of monitoring after three decades does not allow an appropriate evaluation of these actions. However, the low commercial fishery yields in reservoirs of South and Southeastern Brazil (Petrere Jr and Agostinho, 1993; CESP, 1996; Petrere Jr *et al.*, 2002) and the rarity of large sized migratory species in upper Paraná reservoirs (Agostinho *et al.*, 1994) are indications that results were not satisfactory (Table I). Below, we discuss why such actions were considered and the problems related to each one of them.

Fishery control was considered in order to protect juvenile fish, spawning areas and periods. Efficacy of this action is low, mainly because of the lack of information about what is to be controlled, and limited financial and human resources. Other relevant aspects that affected the efficiency of fishery control were the absence of fisheries monitoring (needed because of their dynamics) and the lack of a clear definition of what was to be protected. As sound data on catch per effort of commercial fisheries are available only for some locations (Okada *et al*., 1996), it is not possible to establish maximum sustainable yield values. These values could be informative about the status of the resource (exploitation) and they could also serve as a base to control fisheries.

Participation of the Sector in enforcement along with the responsible public agencies, and better integration among institutions that work in the same basin, may improve the efficacy of fishery control. Participation of universities and other research institutes in defining regulations to control fishery also have potential to improve this situation. However, the lack of basic information will be solved only with research and monitoring.

Stocking programs using exotic and native species were the main actions taken by the majority of the Sector in last decades. Pragmatism drove these actions for a long time. As the allegation that researches to define proper stocking would delay the actions, several hatcheries were built and personnel was hired to operate them, always expecting to improve (restore) fisheries through stocking with exotics.

In South and Southeastern Brazil, more than 10 species from other basins were introduced, usually after some studies developed in hatcheries of Northeastern Brazil. Wrong species stocked in inadequate places, under natural inappropriate conditions, led these actions to failure. In most cases, stocked species were never caught, showing, at least, wrong allocation of resources. A notable exception was *Plagioscion squamosissimus* (curvina). This species is originally from North Brazil and it virtually presents self sustaining populations along the entire upper Paraná River basin. It is important to all fisheries in the region (Petrere Jr *et al.*, 2002). However, the real effects of this piscivore are still unknown. There are some indications that this species negatively impacted fishery at the Itaipu Reservoir. In this reservoir, *P. squamosissimus* preys intensively on young *Hypophathalmus edentatus* (mapará), the main species in the landings (Agostinho *et al*., 1994; Agostinho and Júlio Jr, 1996).

A recent tendency of the Sector is stocking using native species. But technology to evaluate the success of these stocking programs and the genetic impacts resulting from endogamy is still unavailable. Nevertheless, yield from six reservoirs where stocking was conducted in the last decades is not related to the amount of fish released (CESP, 1996).

Constant failures in stocking programs have led some companies of the Sector to a change in their activities, using the existent infrastructure. Thus, some enterprises have personnel to develop fish farming (producing juvenile fish of exotic and native species for farmers) and/or to study reservoir limnology and ichthyology. Fish farming is an attempt to compensate negative economic impacts resulting from the reservoir formation and it is also expected that farming improves people's perception about the company. However, studies (reservoir limnology and ichthyology) may support fishery administration because they have potential to identify proper actions to be applied and, therefore, be advantageous to manage fishery resources.

Fish ladders were another action taken by the Sector. They were constructed in several small reservoirs and apparently were not appropriate. The biggest problem appears to be that fish ladders were mandatory by law until the 1950's (Law 2250 from Dec 28, 1927; Decree 4390 from Mar 14, 1928 and Decree Law 794 from Oct 19, 1938). It was written: "Whoever builds a dam in any river or stream, for any purpose, is obliged to construct a fish ladder to allow fish to move upstream the dam". This generalization was a mistake and led to several problems. The functioning of fish ladders depends on their technical features (such as type, slope, discharge, position in relation to the dam) and the nature of the ichthyofauna. Some fish ladders were built without technical and scientific knowledge about themselves nor fish species, resulting in loss of resources, efforts and opportunities. For example, in that period, a fish ladder was constructed just above a 70m waterfall in the Negros Stream (São Carlos, São Paulo State), or in streams where no migratory species were present (Charlier, 1957).

Once ladders were built, their performance was not seriously evaluated. Some studies with contradictory conclusions in relation to efficacy of ladders may be found. Godoy (1957, 1975) reported the great efficacy of the ladder constructed at Cachoeira das Emas (Pirassununga, São Paulo State). Borghetti *et al*. (1993, 1994) and Fernández *et al*. (in press) found that several species were able to reach the top of a 27.3m experimental ladder constructed just below the Itaipu Dam, but Godinho *et al*. (1991)

TABLE I
FISHERY YIELDS IN ARTISANAL (COMMERCIAL) FISHERY IN SOME RESERVOIRS OF THE UPPER PARANÁ RIVER BASIN

Reservoirs	Itaipu	Barra Bonita	Jupiá	Ibitinga	Promissão	Água Vermelha	Nova Avanhadava
General features							
River	Paraná	Tiête	Paraná	Tiête	Tiête	Grande	Tiête
Closure	1982	1962	1968	1969	1974	1978	1982
Area (km^2)	1350	334	352	114	530	644	217
Residence time (days)	40.0	90.3	6.9	21.6	134.1	62.1	45.0
Artisanal (commercial) fishery							
Total landing (ton/year)	1600	229	166	42	173	184	43
Yield (kg/ha/year)	12.0	7.0	4.7	3.7	3.3	2.9	2.0
Number of species	52	39	34	41	43	34	42
Relative contribution to the artisanal fishery							
Introduced species	20.1	28.3	16.2	25.9	23.8	43.4	34.9
Plagioscion squamosissimus (curvina)	20.1	28.3	11.9	25.4	23.8	30.8	34.7
Cichla monoculus (tucunaré)			4.3	0.5	0.02	2.9	0.2
Oreochromis + *Tilapia* (tilapias)						9.7	
Native species	79.9	71.7	83.8	74.1	76.2	56.6	65.1

Data from CESP (1993), Petrere and Agostinho (1993).

called attention for the low efficacy of the ladder (10.8m high) constructed at the Salto Morais Dam, in the Tijuco River. In all cases, authors reported that the ladder favored some species. However, these studies inform only about the efficacy of transposing a given dam (going up a ladder); they do not consider the importance and effectiveness of the ladders for the conservation of fish stocks upstream. There are no questions on the ability of migratory species passing through ladders, even for heights more than 20m (Borghetti *et al*., 1994). In addition, after reaching the reservoir, fish are able to orient themselves and find the river continuation upstream (Agostinho *et al*., 1993, 2003).

There are indications that ladders may present low efficacy in maintaining fish stocks in a scenario of reservoir cascade, such as the upper Paraná River. Some tributaries in this basin possess areas adequate for spawning, but large migratory species require wetlands (seasonally inundated) during their early stages of ontogeny. These areas are nowadays regulated by dam operation or have been incorporated into agriculture.

Another fundamental issue is the recruitment of fish stocks downstream from a dam. Fish ladders and elevators (built recently) potentially allow adult fish to migrate downstream, but we do not believe that their progeny will do the same. Differently from salmonids from the Northern Hemisphere, from which ladders in Brazil were conceived, eggs and larvae of large migratory species of the Neotropical region, especially those from the upper Paraná River, passively drift downriver from spawning places. Thus, eggs and larvae usually drift from the uppermost stretches of tributaries (spawning places) to the lower courses where floodplains (nurseries) are located (when not inundated by a reservoir). We do not believe that larvae go through the lentic areas of reservoirs, with clear water and great number of small predatory species. There are few data available to properly address this question, but it is expected that ladders do reduce the number of spawners and recruitment of stocks downstream from the dams. Still, there is the possibility of not spawning upstream, especially when floodplains (nurseries) are not available.

Perspectives

The understanding that reservoirs have low biological production dominated management actions until the early 1970's. This led the Sector and Public Institutions related to fishery management to implement broad and intense stocking programs. The "biological desert" paradigm that was abandoned in the 1940's in the United States (Miranda, 1996) considered that, after a high initial productivity, reservoirs become more and more unproductive. This called for continuous stocking programs and the introduction to reservoirs of species that were better "adapted". This belief was so profound that hatcheries were common features in dams under construction.

The lack of information on yield did not allow an evaluation of the paradigm. Only recently some results of landed fish from commercial fisheries were published (CESP, 1993; Petrere Jr and Agostinho, 1993; Agostinho, 1994a, b; Petrere Jr, 1996). These studies reported that after the impoundment, reservoirs were highly productive ("trophic upsurge period") with high fishery yields; a tendency to decrease was later verified, but in most cases, at levels higher than the yields from the river where they were formed. These publications were a final demonstration that species introduction and stocking programs conducted in the last 30 years failed and that native species, usually ignored in the stocking programs, constitute up to 84% of recent landings (Table I).

This was an indication that the ongoing paradigm ("biological desert") was not the adequate conceptual system to guide management of reservoir fisheries. Then, the knowledge accumulated in the last 30 years in Brazil worked as an anomaly (according to Kuhn, 1969) and it was the first sign that an incremental change was necessary. This would be the adoption of the "biomanipulation" paradigm (Miranda, 1996), still to be consolidated among managers of the Sector. Under the umbrella of this paradigm, actions should consider management of environment (spawning places and nurseries), populations (stocking, reduction of non-desired species) and fisheries (control). Stocking is still a valid tool, but it should be performed after detailed analysis of why fishery yield is low (see Gomes and Miranda, 2001).

This management approach appears to be advantageous for Brazil (and may be so for other South American countries) because it incorporates a broader view of the fishery system (environment, fishermen and fish). It also assumes monitoring and system feedback. In addition, to be effective, it needs to consider the watershed concept and multiple uses, recognizing biological, political and socioeconomic limitations in the decision making process.

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