A quantitative approach to subsidize the precautionary management of the small-scale fisheries in Itaipu reservoir, Brazil

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Introduction

Professional inland fisheries are an important economic activity in the region of Itaipu reservoir (135000 ha of inundated area, 12600 MW of nominal generation power), located on the Paraná River at the Brazil/Paraguay border (Paraná River is 4695 km long; Paraná/La Plata basin has a drainage area of 2800000 km^2). The dam was closed in 1982, and before this landing data were scarce. In 1985 it an agreement was set between the UEM (Universidade Estadual de Maringá) and ITAIPUBINACIONAL (the Brazilian/Paraguayan Agency that operates the dam) to collect landing data (FUEM 2002). In 1998, 619 professional fishermen landed 1192t of fish, of 10 commercial species, captured by nets and hooks (Petrere **et al**. 2002).

Due to legal exigencies, after the dam closure, Itaipu was obligated to the royalties' payment to the municipalities in the region of the reservoir. In practice, between 1991 and 2001, it was observed a strong negative relation between the amount of royalties transferred to the municipalities and the fishing effort (of professional fisheries). Hypothetically, a fall in the fishing effort can occurred due to the increase of employment level of the population of these municipalities in other sectors of economy affected by the royalties (for example: agriculture and commerce).

In this context, the aim of this paper is to propose a preliminary bio-mathematical model to subsidize the formulation of guidelines, based on the statements of precautionary management, as the predominant orientation in the juridical literature. Specifically, it is intended to elaborate a model via the software Vensim PLE to describe and predicting small-scale fisheries consequences upon the reservoir fish stock, and to test the relation between the decrease of fishing effort and Itaipu royalties' payment to the municipalities in the region of the reservoir via a regression model.

Scenario

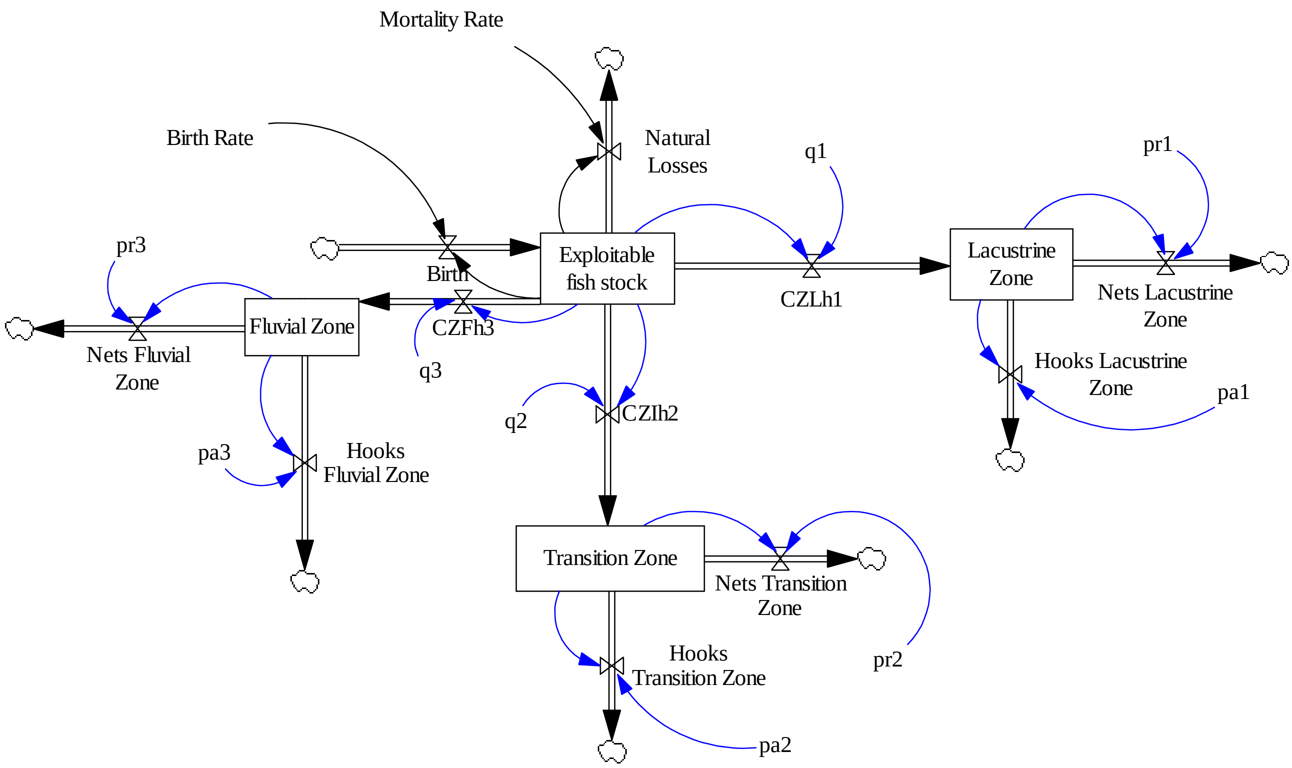
According to Okada **et al**. (2005) the reservoir consists of 12 fishing areas, distributed in 3 zones: fluvial (influenced by Paraná River), transition (influenced by the tributaries) and lacustrine (near the dam). The main fishing gears employed are nets and hooks. It is important to stress that the Paraguayan side was not considered in the model, due to the lack of information. An annual fishing ban during the reproduction period was started in 2000 continuing annually from November to February.

In the 1990 there were 509 fishermen month^{-1} on average working in the reservoir. This number fell to approximately 365 fishermen month^{-1} between 2000 and 2002, as a consequence of the fishing ban. There were also differences in fishermen densities in the zones of the reservoir. The lacustrine zone concentrates 42% of the fishermen, the fluvial zone 41% and the transition zone, 17% (FUEM, 2002). It is important to point out that the density of fishermen in the reservoir declined in the subsequent years, possibly due to the low fishery economic income (Agostinho **et al.**, 1999).

The models

Fishery model

Figure 1 presents the flowchart of the proposed model to describe the fisheries in Itaipu reservoir. The baseline conditions of the model were established according FUEM (2002) for description of the scenario (Table 1).



Where: pr_i (proportion of net fisheries at the zone *i*); pa_i (proportion of hook fisheries at the zone *i*); q_i (proportion of landings at the zone *i*); cz_i (total landings at the zone *i*).

Figure 1. Flowchart of the considered model to describe the fisheries in Itaipu Reservoir.

Table 1. Baseline conditions for the simulation of the model presented in Figure 1.

# ***Equation***	***Units***	***Observations***
(01) Birth=(Exploitable fish stock*Birth Rate)+1560	Tons/YEAR	
(02) Birth Rate=0.0025	%	
(03) $CZFh_3=q_3$*Exploitable fish stock	Tons/YEAR	Landings in fluvial zone.
(04) $CZIh_2$=Exploitable fish stock*q_2	Tons/YEAR	Landings in transition zone.
(05) $CZLh_1$=Exploitable fish stock*q_1	Tons/YEAR	Landings lacustrine zone.
(06) Exploitable fish stock=INTEG (Birth-$CZLh_1$-$CZIh_2$-$CZFh_3$-Natural Losses, 1560)	Tons/YEAR	Exploitable fish stock was considered as the same level of MSY (1560t).
(07) FINAL TIME = 10	YEAR	The final time for the simulation.
(08) Fluvial Zone=INTEG (+$CZFh_3$-Hooks Fluvial Zone-Nets Fluvial Zone, 0)	Tons/YEAR	Total landings of fluvial zone.
(09) Hooks Fluvial Zone=Fluvial Zone*pa_3	%	
(10) Hooks Lacustrine Zone=Lacustrine Zone*pa_1	%	
(11) Hooks Transition Zone=Transition Zone*pa_2	%	
(12) INITIAL TIME = 0	YEAR	The initial time for the simulation.
(13) Lacustrine Zone= INTEG (+$CZLh_1$-Hooks Lacustrine Zone-Nets Lacustrine Zone, 0)	Tons/YEAR	
(14) Mortality Rate=0.001	%	
(15) Natural Losses=Exploitable fish stock*Mortality Rate	Tons/YEAR	
(16) Nets Fluvial Zone=Fluvial Zone*pr_3	%	
(17) Nets Lacustrine Zone=Lacustrine Zone*pr_1	%	

(18)	Nets Transition Zone=Transition Zone*pr_2	%	
(19)	pa_1=0.3	%	
(20)	pa_2=0.3	%	
(21)	pa_3=0.3	%	
(22)	pr_1=0.7	%	
(23)	pr_2=0.7	%	
(24)	pr_3=0.7	%	
(25)	q_1=0.4512	%	
(26)	q_2=0.3504	%	
(27)	q_3=0.3984	%	
(28)	SAVEPER = TIME STEP	YEAR	The frequency with which output is stored.
(29)	TIME STEP = 1	YEAR	The time step for the simulation.
(30)	Transition Zone=INTEG (+$CZIh_2$-Hooks Transition Zone-Nets Transition Zone, 0)	Tons/YEAR	

Regression model: royalties and fishery landings

Aiming to test the influence of the royalties over the fishing effort (of professional fisheries), it was elaborated a regression model between the reservoir landings and the royalties transference to the municipalities. Equation 1 presents the model:

$$PAT = RAT + \varepsilon$$

Equation 1, where:

$PAT =$ Total annual production (landings) of the reservoir;

$RAT =$ Amounts of annual transference of royalties.

The data used to test this model is in Table 2.

Table 2. Landings and royalties data.

Year	***Production of the reservoir (t) - PAT***	***Royalties transference to municipalities of State of Paraná – RAT (US$)***
1991	1589	7740
1992	1663	11215
1993	1542	7842
1994	1297	42602
1995	1373	42635
1996	1411	57571
1997	1192	71518
1998	.	71906
1999	1182	73493
2000	1253	75562
2001	1051	74169
2002	.	80568
2003	.	61840
2004	.	31020

Results

The result of the simulation is presented in Figure 2, considering the peculiarities of the three zones of the reservoir. The exploitable fish stock was considered at the same level of the maximum sustainable yield, estimated by Okada **et al**. (1996) and FUEM (2002) as 1560t year^{-1}. It was set as an initial value and simulated an increase of the fishing effort of 20% year, during 10 years. The results indicated that the disruption of the exploitable fish stock is immediate. The mathematical routines, allowed the insertion of economic sub-routines as shadow variables in the reservoir zones. It is important to point out that this scenario was simulated with an opposite tendency, in fact, FUEM (2002) mentions that fishing effort has been reduced from 1997 to 2001. During 2004 the total production was 632.4t, with, in average, 332 fishermen month^{-1} working in the reservoir (unpublished data). This scenario was developed according to the precautionary management statements (Camargo & Petrere, 2004), allowing the fisheries officers to estimate different levels of fish stocks exploitation and its consequences.

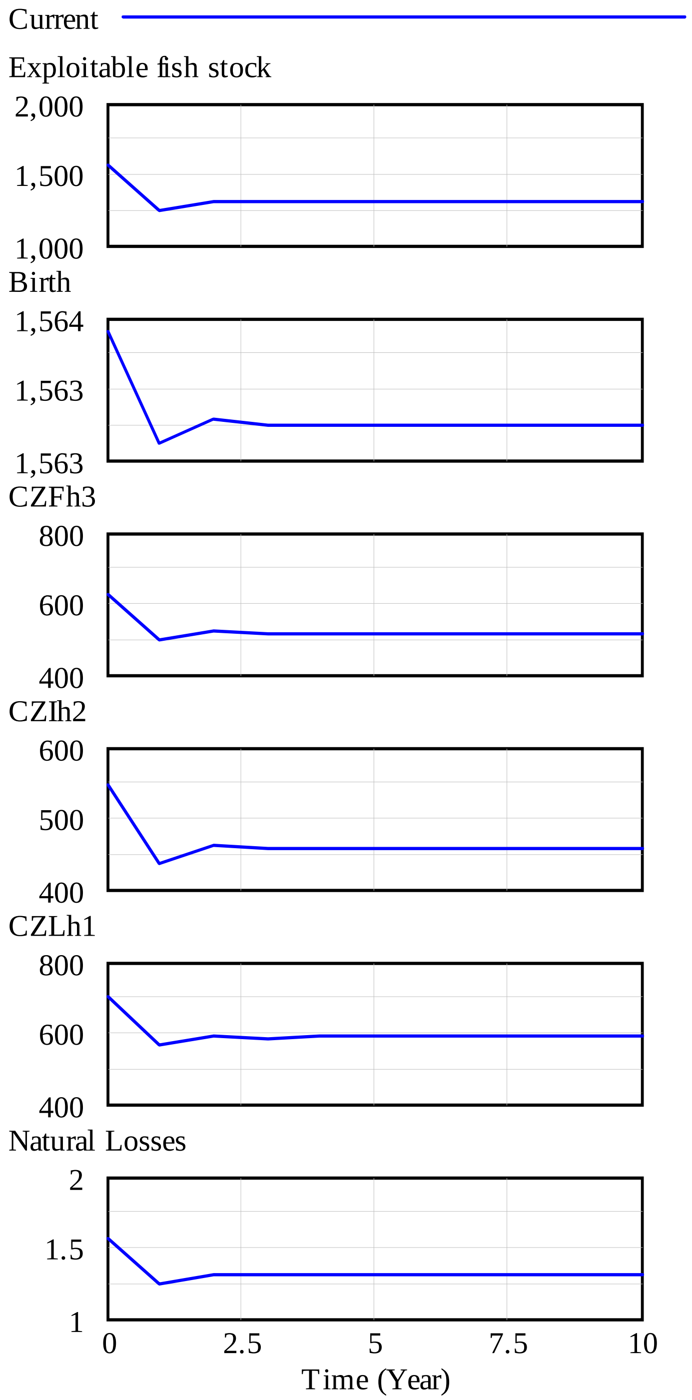


Figure 2. Result of the simulation for exploitable fish stock=1560t year^{-1} with 20% of increment in the fishing effort.

According to Figure 2 it is possible to conclude that the model, under the conditions described above, is stable. On the other hand, any increment on fishing effort (≥20%) will disrupt the exploitable fish stock in short period. This behavior enforces the necessity to adopt precautionary actions, as stated in the Code of Conduct for Responsible Fisheries

(FAO), that was validated in Brazil by the Decree 5.382/2005, aiming to promote social and environmental sustainability of the professional fisheries.

On the other hand, it was observed that the increment of fishing effort is closely related to Itaipu royalties' payment to the municipalities in the region of the reservoir. This relation was tested in a linear regression model. The total annual production of the reservoir from 1991 to 2001 was set as the dependent variable and the total annual amount of royalties paid to 11 municipalities of the Brazilian side (the Paraguayan margin is poorly inhabited and with three conservation units), during the same period, was set as the independent variable. The total annual production (landings) of the reservoir (Y), in average, from 1991 to 2001 was 1355.3t (n=10; minimum=1051t; maximum=1663t), and the total annual royalties payment (X), during the same period, was in average US$4 8750.3, (n=11; minimum=US$7740.0; maximum=US$75562.0). This regression analysis presented a negative relationship (Y=1648.8-0.006*X; r^2=0.838**; s^2_{YX} = 7092.9; n = 10). It means that the local population prefers to work in other activities. In this case, small-scale fisheries are an alternative to unemployment in the urban zone. This fact indicates the importance of the royalties to these cities, enhancing the employment level of the population, contributing indirectly to the maintenance of the present levels of fishing effort.

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