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Short communication

Fishery yield relative to chlorophyll *a* in reservoirs of the Upper Paraná River, Brazil

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Abstract

Fishery yields in reservoirs of the Upper Paraná River basin are small when compared to those in other parts of the world. Several hypotheses have been formulated to explain the small yields, but low primary production has not been seriously considered as a possibility. In a sample of seven reservoirs, yield was directly related to fishing effort and chlorophyll *a* concentration; thus, enhancement of these factors may boost yield. However, primary production is difficult to augment in large reservoirs, plus current levels of effort seem to be nearing maximum sustainable yields in some reservoirs, and therefore increased fishing effort is not likely to boost yields to levels recorded in other geographical regions. Low primary production in reservoirs of the Upper Paraná River basin appears to be a result of interactions between physical characteristics of the reservoirs and climatic conditions of the region. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Fishery yield; Effort; Chlorophyll *a*; Reservoirs; Paraná River

1. Introduction

Fishery yields from reservoirs of the Upper Paraná River are low relative to reservoirs in other parts of the world. Estimates made during surveys conducted since 1986 indicate annual commercial yield averages 9 kg ha^{-1} ($N = 10$ reservoirs; Oldani, 1994; Agostinho et al., 1995). Conversely, annual yield from commercial fisheries average near 100 kg ha^{-1} in African reservoirs (Marshal, 1984), 150 kg ha^{-1} in reservoirs of northeastern Brazil (Paiva et al., 1994), 120 kg ha^{-1} in Asian reservoirs (De Silva, 1987), and 20 kg ha^{-1} in recreational fisheries in US reservoirs (Miranda, 1999). Possible reasons for low yields include the absence of lacustrine-adapted species, complexity of the food web, high number of predatory species, and low fishing effort (Fernando and Holčík, 1982; Paiva et al., 1994; Agostinho and Zalewski, 1995; Agostinho et al., 1995; Petrere, 1996).

Primary production is linked to fishery yield through bottom-up processes (Horne and Goldman, 1994). Primary production has not been seriously considered as a factor that can potentially limit fishery yield in reservoirs of the Upper Paraná River. Nevertheless, elsewhere in the world it has been shown to affect fish production, standing crop and yield (Melack, 1976; Liang et al., 1981; Hoyer and Jones, 1983; Carline, 1986; Downing et al., 1990; Quirós, 1990; Moreau and De Silva, 1991; Maceina et al., 1996).

The purpose of this study was to investigate if fishery yields in reservoirs of the Upper Paraná River basin were strongly related to phytoplankton biomass.

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We work with a small, preliminary sample size because fishery data from reservoirs in the Upper Paraná River basin are limited and difficult to obtain.

2. Methods

2.1. Study region

The Paraná River (4695 km long; 2.8×10^8 ha drainage area; 18–34°S; 45–68°W) (Fig. 1) is formed by the junction of the Grande and Paranaíba rivers in south-central Brazil, and flows into the La Plata River in northern Argentina. It is the 10th longest river in the world and second longest in South America. The Upper Paraná River includes approximately the first third of the Paraná River basin (all inside Brazilian territory, except for a stretch within Itaipu Reservoir, which borders with Paraguay). In this region there are 130 major reservoirs (dam > 10 m height), among these 20% are larger than 10 000 ha.

The reservoirs included in this study (Fig. 1) were impounded mainly to produce electricity. Most of the reservoirs are located on the Tiête River (Billings, impounded in 1925; Barra Bonita in 1962; Ibitinga in 1969; Promissão in 1974; Nova Avanhandava in 1982; Três Irmãos in 1990), and one in the Upper Paraná main channel (Itaipu, impounded in 1982). The seven study reservoirs averaged 48 700 ha (range 11 400–135 000) in surface area, 15.6×10^6 ha (range 0.56×10^6–82×10^6) in drainage area, 12.6 m (range 8.1–21.0) in mean depth, and 132 days (range 1–709)

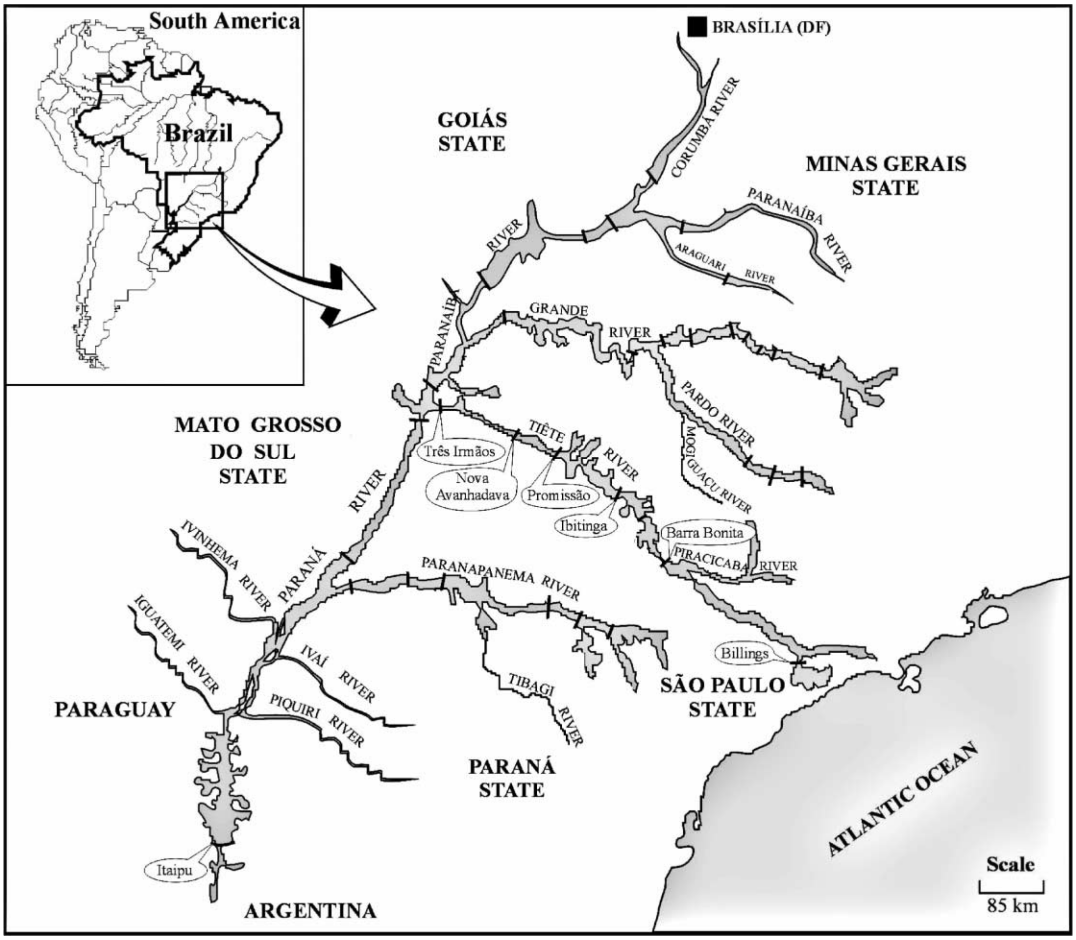

Fig. 1. Map of Brazil identifying the Upper Paraná River basin and the locations of the study reservoirs.

in retention time. These and other physical descriptors of the reservoirs influenced phytoplankton biomass; those relations were analyzed by Gomes and Miranda (in press).

2.2. *Data sources and analysis*

Data on phytoplankton biomass (indexed as chlorophyll *a* concentration in water), fishing effort and yield collected during 1986–1996 were available for the seven reservoirs. Chlorophyll *a* estimates were obtained from São Paulo State Hydroelectric Company (CESP, 1996), Agostinho et al. (1995), and Minte-Vera (1997). In all reservoirs, concentration of chlorophyll *a* uncorrected for phaeophytin, was measured according to Golterman et al. (1978).

Fishery surveys were based on self-reporting logbooks that recorded species, weight, days fished, and gear. Each fisher was paid to keep a logbook on daily catch (species, weight) and effort (gear, quantity). To enhance quality of the data (1) fishers received orientation from a biologist on how to record information in the logbook, (2) one or more fishers (depending on the number of fisher colonies) were hired to review logbook entries daily, and (3) a biologist visited the reservoir monthly to verify compliance. About 40 species were targeted for harvest principally with gill nets, but also cast nets and long lines. Additional details about the fishery survey methods, as well as original data sets, are included in CESP (1996), Agostinho et al. (1995), and Minte-Vera (1997).

Analysis of the relation between chlorophyll *a* and fishery yield assumes constant effort. Because effort varied among the study reservoirs, this variable was incorporated into the analysis to standardize yield. Effort was estimated as the total number of days fished in a year by all fishers, and expressed on an area basis by dividing by the total hectares in the reservoirs. Yield was estimated as the total catch (kg) by all fishers in a year and standardized on a per reservoir area basis. We assumed that fisheries covered each entire reservoir, or that sufficient movement of fish occurred between fished and unfished areas in each reservoir.

We applied regression analysis to identify if fishery yield (dependent variable) was related to chlorophyll *a* concentration (independent variable) while accounting for variable effort (covariate). Regression residuals were analyzed to identify deviations from linearity and model suitability. Data were $\log_e$ transformed for analysis to linearize relations and homogenize variances (Peters, 1986).

3. Results

Data were available for an average of 6 yr of sampling per reservoir, ranging from 1 to 10 yr (Table 1). Chlorophyll *a*, fishing effort and yield in the study reservoirs exhibited ample dispersion. Chlorophyll *a* averaged 6.29 $\mu g\,l^{-1}$ and ranged from 2.05 to 22.00. Fishing effort averaged 0.32 days ha^{-1} and ranged from 0.07 to 0.73. Yield averaged 9.1 kg ha^{-1} and ranged from 2.2 to 24.0.

Billings Reservoir, a highly eutrophic system within the São Paulo Metropolitan Area, exhibited the highest yield (24 kg ha^{-1}). Itaipu Reservoir presented the second highest yield (10.9 kg ha^{-1}) supported by the highest effort (0.73 days ha^{-1}) under relatively low concentration of chlorophyll *a* (average $= 3.6\,g\,l^{-1}$).

Table 1
Mean chlorophyll *a*, effort, and yield estimates in the study reservoirs of the Upper Paraná River basin. Values in parentheses represent 1 S.E.; *N*: number of years the reservoir was sampled

Reservoir	Chlorophyll *a* ($\mu g\,l^{-1}$)	Effort (days ha^{-1})	Yield (kg ha^{-1})	*N*	Source
Barra Bonita	9.00 (7.22)	0.26 (0.040)	9.4 (2.58)	6	CESP (1996)
Billings	22.00	0.57	24.0	1	Minte-Vera (1997)
Ibitinga	2.94 (1.57)	0.21 (0.073)	5.0 (2.01)	7	CESP (1996)
Itaipu	3.60 ([a])	0.73 (0.130)	10.9 (0.68)	7	Agostinho et al. (1995)
Nova Avanhandava	2.17 (1.16)	0.21 (0.128)	5.3 (3.51)	8	CESP (1996)
Promissão	2.24 (1.62)	0.19 (0.167)	6.9 (6.07)	10	CESP (1996)
Três Irmãos	2.05 (2.13)	0.07 (0.013)	2.2 (0.73)	5	CESP (1996)

[a] S.E. was not reported by source.

Table 2
Relationship between $\log_e$ yield (dependent variable), $\log_e$ effort and $\log_e$ chlorophyll *a* for seven reservoirs of the Upper Paraná River basin[a]

Independent variable	Slope coefficient	S.E.	Partial r^2	*P*-value
Intercept	2.236	0.36		<0.01
Effort	0.591	0.15	0.79	0.02
Chlorophyll *a*	0.388	0.13	0.69	0.04

[a] Partial r^2 identifies the proportion of the variability explained by one independent variable while holding the other one constant. The *P*-value identifies the probability of obtaining a larger *F* or *t*-statistic when testing Ho: slope coefficient = 0. For the overall model $r^2 = 0.94$ and $P = 0.004$.

Yield in Billings Reservoir (Minte-Vera, 1997) included mainly the exotic Nile tilapia *Oreochromis niloticus* introduced from Africa. For the other reservoirs in the basin the most important species in the landings was the exotic sciaenid *Plagioscion squamosissimus*, introduced from the Amazon basin. Other species commonly observed in the harvest included the prochilodontid *Prochilodus lineatus*, and the catfishes *Hypophthalmus edentatus*, *Pterodoras granulosus*, *Pimelodus maculatus* and *Iheringichthys labrosus*, all natives to the Upper Paraná River.

Yield was directly related to effort and chlorophyll *a* (Table 2). Combined, these two independent variables accounted for 94% of the variability in yield in the seven study reservoirs. Partial r^2 values (variability explained by the independent variable when the other variable is held constant) were 0.79 for effort and 0.69 for chlorophyll *a*. The correlation between the two independent variables was 0.59 ($P = 0.16$); thus, multicollinearity was not a problem (condition indexes <9). This relation also demonstrated that for equal levels of chlorophyll *a*, greater efforts sustained higher yields, suggesting that, for some reservoirs yield may be increased through additional fishing effort.

4. Discussion

There have been many attempts to model fishery yields as a function of phytoplankton biomass, or indicators of it. Variables such as phytoplankton biomass and production often are better predictors of fishery yield than physical, chemical, hydrological, morphometrical, or edaphical variables (Melack, 1976; Liang et al., 1981; Hecky et al., 1981; Hanson and Legget, 1982; Oglesby, 1982; Carline, 1986; Downing et al., 1990; Moreau and De Silva, 1991). Such variables are also superior in terms of the generalities and insights they give into the nature of the biological processes operating (Hanson and Legget, 1982; Downing et al., 1990). Thus, the relation between chlorophyll *a* and fishery yield identified in the study reservoirs is not a new finding; however, it is the first indication that the prevailing low phytoplankton biomass in reservoirs of the Upper Paraná River basin may be an important factor limiting fishery yields. Factors other than phytoplankton biomass and effort such as fish assemblage characteristics (community composition, complexity of food webs, and efficiency of energy transference among trophic levels) may also have bearing on fishery yield (Ryther, 1969; Fernando and Holčík, 1982; Smith, 1995).

Our model predicted that other than by increasing chlorophyll *a* levels, yield might be enhanced by increasing fishing effort. Fishing effort is generally low in reservoirs of the Upper Paraná River ($\text{mean} = 0.2\,\text{fishers}\,\text{km}^{-2}\,\text{yr}^{-1}$) relative to those reported for northeast Brazil (3.2) and Africa (1.5) (Petrere, 1996). Fish stocks in South American rivers exposed to fishing efforts lower than 0.5 fishers $\text{km}^{-2}\,\text{yr}^{-1}$ have been considered relatively unexploited (Welcomme, 1990), but such guidelines may not apply directly to reservoirs. Studies at Itaipu Reservoir suggest that fishery yield is at or near its maximum with an effort of 0.6 fishers $\text{km}^{-2}\,\text{yr}^{-1}$, and additional effort could lead to reductions in yield through growth and recruitment overfishing (Okada et al., 1996; Miranda et al., 2000). Therefore, in some reservoirs fishery yield may be increased through increases in fishing effort; however, because maximum sustainable yield is ostensibly not drastically higher than current yields, boosts in fishing effort are not expected to increase yield to levels recorded in northeastern Brazil or Africa.

Effort aside, a major limitation to fishery yield seems to be low primary production indexed by low phytoplankton biomass. Despite adequate levels of essential nutrients, low phytoplankton biomass seems limited by physical characteristics of the reservoirs and climatic conditions (Gomes and Miranda, in press). To maximize hydroelectric production, dams in the Upper Paraná River basin have been constructed in high-order rivers; thus, reservoirs generally have large drainage and surface areas, are deep, and have large volume, low retention time, and high discharge. The rainy season normally begins in early spring (October; Rumney, 1968) prompting increased discharges that trigger the spawning season. Along with discharge, nutrients and abiogenic inputs increase, peak in late spring to mid-summer (December–February), and decrease coinciding with rises in chlorophyll *a* in late fall when dry weather returns in May. Because discharges do not subside until late summer to early fall, chlorophyll *a* levels do not rise until late fall, several months after the peak in temperature and after the post-spawning period. This creates a mismatch between temperature, discharge, and phytoplankton production that potentially limits production of lacustrine-adapted fish species to support reservoir fisheries.

The flood pulse seems to have negative consequences in reservoirs of the Upper Paraná River. Within a reservoir the flood pulse increases already high discharge rates, potentially restraining primary production through light limitations, horizontal advective losses, and vertical advective losses prompted by possible coflocculation of phytoplankton and suspended colloids. In a river, these effects are alleviated by lateral expansion of the discharge into the floodplain, allowing diminished flow and abiogenic turbidity. Such constraints on primary production may be the greatest limitation on fishery yields in Upper Paraná River reservoirs.

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