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Modeling energy flow in a large Neotropical reservoir: a tool do evaluate fishing and stability

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Recently, there is an increasing perception that the ecosystem approach gives important insights to support fisheries stock assessment and management. This paper aims to quantify energy flows in the Itaipu Reservoir (Brazil) and to simulate increase of the fishing effort of some species, using Ecopath with Ecosim software, which could allow inferences on stability. Therefore, two steady-state Itaipu models were built (1983-87 and 1988-92). Results showed that: a) there are no differences between models, and results on aging trends do not vary over time indicating that fishery does not alter the ecosystem as a whole; b) results of fisheries simulations are approximate to mono-specific stock assessment for the same species and periods; c) many authors believe that tropical ecosystems are environments where biotic and abiotic oscillations are annual and sometimes unexpected, but the results found for the Itaipu Reservoir indicate that stability was met after 16 years.

Nos dias atuais, aumenta a percepção que a análise ecossistêmica fornece importantes esclarecimentos na avaliação e manejo de estoques pesqueiros. Este trabalho objetiva quantificar o fluxo de energia na teia trófica do reservatório de Itaipu e simular o aumento de pesca de algumas espécies usando o programa "Ecopath com Ecosim", que permite inferências sobre a estabilidade do sistema. Desta forma, dois modelos de "estado-estacionário" foram construídos (o primeiro para o período 1983-87 e o outro para 1988-92). Os resultados mostraram que: a) não há diferenças entre os modelos e os resultados sobre tendências de amadurecimento não variam com o tempo indicando que a pesca não altera o sistema como um todo; b) os resultados de simulação de pesca se aproximam de avaliações mono-específicas, realizadas por outros autores, com dados de mesmas espécies e períodos; c) muitos autores acreditam que reservatórios tropicais são ambientes submetidos a oscilações antrópicas que alteram grandemente sua dinâmica dificultando a estabilidade, mas os resultados para o reservatório de Itaipu indicam que a estabilidade foi encontrada 16 anos após a sua formação.

Key words: Ecopath, Food web, Fisheries, Ecosystem, Simulation.

Introduction

Trophic ecosystem models allow measurement of trophic flows among various system components (primary producers, consumers and predators) and provide fundamental information on their influences on recycling, primary production and food web (Christensen, 1995). Foundations of this ecosystem approach were established by Odum (1969) and Lindeman (1942), which described development of systems restricted by the Second Law of Thermodynamics and therefore susceptible to simulation.

Recently, there is an increasing recognition that the ecosystem approach gives important insights to support fish stock assessment and management (Christensen & Pauly, 1993; Walters *et al*., 1997; Mace, 2001; Hilborn *et al*., 2003; FAO, 2003). This new approach is called Ecosystem-Based Fishery Management (EBFM), and its overall objective is to maintain the health of aquatic ecosystems and the fisheries they support (Pikitch *et al*., 2004).

Multi-specific policy decisions can be simulated in ecosystem models (Christensen & Pauly, 1998; Heymans *et al*., 2004), and comparisons of these models have increased our understanding on ecosystem functioning and fisheries trends (Vasconcellos *et al*., 1997; Jarre-Teichmann, 1998; Aoki & Mizushima, 2001; Christensen *et al*., 2003).

Although most studies on EBFM deal with marine systems, application of this approach in freshwater is important because inland fisheries are apparently more susceptible to environmental changes and play a fundamental role as food source in many countries (FAO, 2002).

Food web simulation in freshwater ecosystems, especially reservoirs, has aided to test several fisheries management

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scenarios and examined ecological potential to lead to increased production (Moreau *et al*., 2001; Villanueva & Moreau, 2001; Schiemer *et al*., 2001). Modeling reservoirs may be more complicated because they are used by several stakeholders, and, in most of the cases, with contradictory needs (Angelini & Petrere, 2000).

Presently, 90% of the energy consumed in Brazil is produced by dams and 70% of the dams are located in the Paraná River Basin (Okada *et al*., 1996). Although annual fishery yields in reservoirs of the Paraná River is low (9.1 kg ha^{-1}) relative to reservoirs in other parts of the world (Petrere, 1996; Miranda, 1999), fisheries are an important regional economic activity because they supply food for thousands of people.

In the Itaipu Reservoir, commercial fisheries started after its formation (since February 1984), and the number of fisherman along time has oscillated around 900, of which 60% are permanent (Okada *et al*., 2005). Numerous studies have assessed the fishery in Itaipu Reservoir (Agostinho *et al*., 1994; Okada *et al*., 1996; Gomes & Miranda, 2001; Miranda *et al*., 2000; Gomes *et al*., 2002; Petrere *et al*., 2002), but none adopted the food web approach.

In this study, we applied the ecosystem approach to data obtained in the Itaipu Reservoir. Energy flows were quantified for two different periods (two steady-state models; 1983-87 and 1988-92). These models were compared in order to evaluate trophic interactions and aging effects. In addition, simulations considering effects of increasing fishing effort were done. We expect to answer the following questions: i) is the ecosystem approach useful to guide management of reservoir fisheries? and ii) is there, for the Itaipu Reservoir, any sign of stability? For the second question, we assume if there is no difference between the models, some sort of stability was already reached.

Fig. 1. Itaipu Reservoir, its tributaries and the upper Paraná River Floodplain upstream (spawning areas for the reservoir migratory fish species).

Methods

Study Area

The Itaipu Dam was concluded in October 1982 and it is located on the Brazilian- Paraguayan border (Fig. 1). The resulting Itaipu Reservoir has a surface area of 1350 km^2, mean depth of 22 m and an average hydraulic retention time of approximately 40 days. It is considered mesotrophic water body with low phosphorus concentration and limited primary production (Andrade *et al*., 1988).

Upstream from the Itaipu Reservoir, there is an extensive floodplain, which represents the last non-dammed stretch of the Paraná River within the Brazilian territory. This stretch is very important for fish populations in the reservoir because many migratory species use the area as nursery (Baumgartner *et al*., 2004).

Model

We used Ecopath software (Christensen & Pauly, 1993) to construct food web models. Ecopath combines the work developed by Polovina (1984) to estimate biomass and consumption of various elements of an aquatic ecosystem, based on the theory for analysis of flows among elements of an ecosystem (Ulanowicz, 1986). A basic requirement in these models is that input to each group is equal to output (equilibrium conditions). Then, a series of biomass budget equations are determined for each group as:

Production – all predation on each grouping – non-predatory mortality – all exports = 0

The resulting budget equations are transformed into simultaneous equations following the formula:

$$0 = B_i * PB_i * EE_i - Y_i +_j (B_j * QB_j * DC_{ji}) \quad (1)$$

where: B_i is the biomass of (i), PB_i is the production/biomass ratio of (i) that is equal to total mortality rate (Z_i), EE_i – ecotrophic efficiency, i.e. fraction of production of (i) that is consumed, Y_i is the yield of (i) or its catch in weight, B_j is the biomass of predators, QB_j is food consumption per unit of biomass for consumer *j* and DC_{ji} is the fraction of *i* in the diet of *j*.

Equation (1) was proposed by Walters *et al.* (1997) that modified the original model, including a routine (Ecosim), which allows simulating fisheries in several management scenarios. The data required for Ecopath with Ecosim were gathered and standardized to the unit ton*km^{-2} or ton*km^{-2}*year^{-1}. Then, two Ecopath models were built, the Itaipu-1, for the first period (1983-1987) and the Itaipu-2, for the second period (1988-1992).

Data Source and model Components

Length-frequency data for the most abundant species of the Itaipu Reservoir for the periods 1983-87 and 1988-1992 were obtained by NUPELIA (Research Nucleus in Limnology, Ichthyology and Aquaculture, Maringá State University, Brazil). In general, intense fishing surveys were carried out in the studied area using different combinations of fishing gears (for more details see Agostinho *et al.*, 1994 and Agostinho *et al.*, 2001).

Initial estimates of fish biomass were determined by the Ecotrophic Efficiency and Ecopath calculated the biomass. A high value (0.99 or 0.9) was considered for fishes with trophic level as many as 2 or 2.5 due to the expected importance of these groups as food of several piscivores groups. For commercially important species, biomass values were calculated using VPA (Virtual Population Analysis). PB (or Z) values were estimated using FISAT (FAO-ICLARM 1996) and QB values by regression from Palomares & Pauly (1998). For more details, see Angelini & Agostinho (2005a, b).

Non-fish compartments estimates were made based on the literature. Phytoplankton was quoted in Andrade *et al.* (1988), Thomaz (1991) and Thomaz *et al.* (1997). Other sources were used: Cook (1990), Thomaz & Bini (1999), Thomaz *et al.* (1999) for macrophytes; Rodrigues (1998) for periphyton; Cummins & Klug (1979), Takeda *et al.* (1997), Mihuc (1997) and Brey (1999) for benthos; Tundisi (1986), Sipaúba – Tavares *et al.* (1994), Angelini *et al.* (1996) and Lansac – Tôha *et al.* (1997) for zooplankton; Silva Jr. (1998) for insects. Data were transformed in ton*km^{-2} using a conversion table (Optiz, 1991).

Diet composition matrix for fish was established according to Hahn *et al.* (1997) and Agostinho *et al.* (1997), whose data partly refers to the Upper Paraná River Floodplain, which presents a similar fish fauna.

Thirty two components were used for each model, as follows: *i)* seven are non-fish compartments; *ii)* three are aggregated by feeding habit (Other detritivores, Other insectivores, Other omnivores), because in Itaipu there are 80 fish species; *iii)* in order to get a balanced model, two compartments are composed of grouped species: Group 1: *Pimelodus maculatus* (Lacepéde, 1803), *Plagioscion squamosissimus* (Heckel, 1840) and *Serrasalmus marginatus* (Valenciennes, 1836), Group 2: *Ageneiosus ucayalensis* (Casteunal, 1855), Other piscivores, *Zungaro zungaro* (Humboldt, 1821) and *Pseudoplatystoma corruscans* (Spix & Agassiz, 1829). These groupings helped to balance the models, minimizing redundancy between piscivores groups (Angelini & Agostinho, 2005b)*; iv)* other components are: *Loricaria* sp., *Schizodon boreilii* (Boulenger, 1900), *Hypostomus* spp, *Prochilodus lineatus* (Valenciennes, 1836), *Iheringichthys labrosus* (Lütken, 1874), *Hypophthalmus edentatus* (Spix & Agassiz, 1829), *Trachydoras paraguayensis* (Eignmann & Ward, 1907), *Leporinus friderici* (Bloch, 1794), *Leporinus obtusidens* (Valenciennes, 1836), *Pterodoras granulosus* (Valenciennes, 1836), *Astyanax altiparanae* (Garutti & Britski, 2000), *Auchenipterus nuchalis* (Spix & Agassiz, 1829), *Acestrohyncus lacustris* (Lütken, 1875), *Hoplias malabaricus* (Bloch, 1794), *Pinirampus pirinampu* (Spix & Agassiz, 1829), *Rhaphiodon vulpinus* (Spix & Agassiz, 1829), *Moenkhausia intermedia* (Eignmann, 1908) *Megalancistrus parananus* (Peters, 1881), *Rhinelepis aspera* (Spix & Agassiz, 1829).

Table 1. Parameters of the ECOPATH models for the Itaipu Reservoir in the two periods: Itaipu-1 (83-87) and Itaipu-2 (88-92). B (Biomass); PB (Production/Biomass); QB (Consumption/Biomass); EE (Ecotrophic Efficiency). Values in brackets are estimated by Ecopath. * Species Grouping: Group 1: *P. maculatus*, *P. squamosissimus, S. marginatus;* Group 2: *A. ucayalensis*; Other piscivores, *Z. zungaro*, *P. corruscans*.

Calibrated Parameters	B (t km^{-2})		PB (year^{-1})		QB (year^{-1})		EE	
Groups Periods	83-87	88-92	83-87	88-92	83-87	88-92	83-87	88-92
Phytoplankton	(0.36)	(0.28)	250.0	250.0	-	-	0.90	0.90
Macrophytes	100.0	100.0	30.0	30.0	-	-	(0.06)	(0.03)
Periphyton	14.80	14.80	40.0	40.0	-	-	(0.16)	(0.17)
Benthos	4.80	4.80	10.4	10.4	40.0	40.0	(0.22)	(0.26)
Insects	(1.72)	(1.57)	25.0	25.0	250.0	250.0	0.70	(0.10)
Zooplankton	(0.52)	(0.38)	54.0	55.0	250.0	250.0	0.70	(0.22)
Loricaria sp.	(0.08)	(0.05)	4.5	6.0	45.0	60.0	0.99	0.99
Schizodon borelii	(0.06)	(0.06)	6.5	5.0	55.0	50.0	0.99	0.99
Hypostomus spp	(0.17)	(0.11)	3.8	3.5	35.0	35.0	0.99	0.99
Prochilodus lineatus	0.60	(0.48)	4.2	3.9	25.0	45.0	(0.63)	(0.96)
Iheringichthys labrosus	(0.04)	(0.08)	4.8	2.8	45.0	19.4	0.99	0.99
Hypophthalmus edentatus	0.65	(0.65)	3.6	1.6	20.9	20.9	(0.42)	(0.63)
Trachydoras paraguayensis	(0.04)	-	3.6	-	55.0	-	0.99	-
Leporinus friderici	(0.06)	(0.21)	1.7	2.8	18.9	19.0	0.99	0.99
Leporinus obtusidens	(0.72)	0.38	2.7	4.0	18.6	30.0	0.99	(0.92)
Parauchenipterus galeatus	(0.18)	(0.47)	5.1	1.4	26.2	26.2	0.99	0.99
Pterodoras granulosus	(0.54)	0.40	2.5	2.1	20.0	16.1	(0.69)	(0.62)
Astyanax altiparanae	(1.66)	(1.14)	2.2	2.6	10.9	10.9	0.99	0.99
Auchenipterus nuchalis	0.06	0.08	6.5	3.0	50.0	10.0	(0.81)	(0.98)
Acestrorhyncus lacustris	0.04	0.12	5.5	2.8	25.0	9.5	(0.81)	(0.97)
Group 2*	0.41	0.31	2.4	2.1	9.1	7.7	(0.94)	(0.93)
Group 1*	1.20	1.03	2.1	1.4	9.2	6.2	(0.58)	(0.77)
Hoplias malabaricus	0.04	0.09	4.9	2.4	17.0	8.7	(0.69)	(0.81)
Pinirampus pirinampu	0.11	0.11	2.0	1.4	7.0	5.0	(0.89)	(0.92)
Rhaphiodon vulpinus	0.09	0.18	3.2	1.6	13.0	7.0	(0.85)	(0.98)
Moenkhausia intermedia	0.16	-	5.0	-	26.0	-	(0.92)	-
Megalancistrus parananus	-	0.35	-	4.00	-	30.0	-	(0.57)
Rhinelepis aspera	-	(0.56)	-	1.44	-	14.0	-	0.99
Other detritivores	(0.31)	(0.07)	4.3	4.30	43.0	43.0	0.99	0.99
Other omnivores	(0.56)	(0.67)	5.0	5.0	33.0	33.0	0.99	0.99
Other insectivores	(0.41)	(0.25)	3.9	3.9	27.0	27.0	0.99	0.99
Detritus	-	-	-		-		(0.14)	(0.13)

Table 2. Trophic level (TL) and diet composition of the compartments for ECOPATH in the Itaipu Reservoir. See Groups in Table 1.

TL		Prey/ Predator	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1.0	1	Phytoplankton			.5	.1	.3	.2	.15		.3		.05	.05		.1	.1								.1		.1			
1.0	2	Macrophytes		.2			.7						.3	.3	.4	.5	.2									.2	.2			
1.0	3	Periphyton	.5							.1																	.05		.1	.1
2.0	4	Benthos				.1			.15	.35			.05	.05		.1				.05					.1		.15	.1		.1
2.0	5	Insects				.2				.2		.15	.2	.2	.6	.1	.3	.7		.02					.1	.6	.3	.2		
2.0	6	Zooplankton								.1	.7	.3				.1	.1	.2		.03						.1	.1	.7		
2.3	7	*Loricaria* sp.	.																.1		.05		.1							
2.0	8	*S. borelli*																	.1		.05		.1							
2.0	9	*Hypostomus* spp.																		.05			.1							
2.2	10	*P. lineatus*																			.1	.2		.2						
2.7	11	*I. labrosus*																	.2	.15										
2.7	12	*H. edentatus*																			.15									
2.5	13	*T.paraguayensis*																					.2							
2.6	14	*L. friderici*																		.05			.15							
2.6	15	*L. obtusidens*															.1					.2								
2.6	16	*P. galeatus*																		.05			.15	.2						
2.3	17	*P. granulosus*																		.05		.2	.1							
2.8	18	*A. altiparanae*											.1	.1					.2	.1	.1		.1	.2						
3.0	19	*A. nuchalis*																	.1		.05									
3.6	20	*A. lacustris*																			.05	.1		.1						
3.4	21	Group 1																		.1	.1									
3.9	22	Group 2																		.05	.1									
3.8	23	*H. malabaricus*																				.2								
3.3	24	*P. pirinampu*																			.05									
3.7	25	*R. vulpinus*																			.05			.1						
2.2	26	other ilio/det																.1	.1					.1						
2.7	27	other insectiv																	.1	.1		.1		.1						
2.6	28	other omnivores											.1	.1			.1		.1	.05	.05									
3.0	29	*M. intermedia*																												
2.0	30	*M. paranamus*															.05				.05									
2.1	31	*R. aspera*															.05				.05									
1.0	32	Detritus	.5	.8	.5	.6		.8	.7	.25		.55	.2	.2		.1				.15					.7	.1	.1		.9	.8

Comparisons and simulations

The ITAIPU-1 (1983-1987) and ITAIPU-2 (1988-1992) models were compared using some ecosystem key features described by Odum (1969). After, using Ecopath with Ecosim, we simulated the ITAIPU-1 model (applying the same landing of ITAIPU-2) for five years, that resulted in the Itaipu-SIM model and showed ecosystem's conditions for 1992. So, biomasses of this later model were compared, through paired t test, with the biomasses of the ITAIPU-2 model (1988-1992). This was done in order to validate the model. In addition, the ITAIPU-2 model was simulated, increasing fishing effort for some compartments, and these results were compared with mono-specific stock assessment models, published in Agostinho *et al.* (1999) and with landing data published in Okada *et al.* (2005).

Original landing from 1998, were put in subroutine "Input-Landing" of the Ecopath and used to calculate initial fishing effort. Landing data were described in ton*km^{-2}*year^{-1} as following: *Prochilodus lineatus*: 0.19, *Hypophthalmus edentatus*: 0.3, *Pterodoras granulosus*: 0.18, *Hoplias malabaricus*: 0.02, *Pinirampus pirinampu*: 0.02 and *Raphiodon vulpinus*: 0.04, Group 1: 0.24, Group 2: 0.05.

Results

Estimates of biomass, production and consumption of the groups are presented in Table 1 for the two models (ITAIPU-1 and ITAIPU-2) and Table 2 summarizes the diet composition and trophic level for both models.

Apparently, the fishing activity conducted in the Itaipu Reservoir does not alter the ecosystem as a whole because attributes that indicate ecosystem maturity are similar in the two models (Table 3).

Biomasses resulting of simulation in ITAIPU-1 (1983-87), for five years, were compared to compartment biomasses of ITAIPU-2 (1988-1992), by paired *t* test, and difference was not significant ($t = 0.52$, $p = 0.60$), validating the simulation.

Fishing effort original, based in landing data from 1998, was multiplied by 2, 3 and 4 in order to simulate different fishery scenarios (Figs. 2a - 2b). It was possible to observe an increment in the biomass of *P. lineatus* that can be explained

Table 3. Attributes of ecosystem maturity for the Itaipu reservoir models. Trend indicates the expected behavior by Odum (1969).

Attributes	ITAIPU-1 1983-87	ITAIPU-2 1988-92	Trend (expected)
Total Primary Production/ Total Respiration	6.3	6.8	= 1
Total Primary Production/ Total Biomass	28.24	28.23	Diminishing
Biomass supported/ Energy Flow	0.016	0.016	Increasing
Finn cycling index (%)	1.92	1.78	Increasing
Total number of cycles	663	801	Increasing
Mean length of cycles	5.01	5.19	Increasing
Transfer efficiency (%)	8.5	9.6	Increasing
Flow from detritus (%)	0.51	0.51	Increasing
Ascendency (%)	46.0	46.8	Diminishing
Overhead (%)	54.0	53.2	Increasing

by the reduction in biomass of its main predator *H. malabaricus* (Trophic Level (TL) = 3.8). *Pinirampus pirinampu* (TL = 3.3) had its biomass increased probably because of the decreasing biomass of its competitor due to its higher catch (Fig. 2a). Group 1, *P. lineatus* and *P. pirinampu* did not alter their biomasses (Fig. 2a) and, therefore, their fishing effort and landing could increase (Fig. 2b).

Figure 3 shows simulated catch and observed catch data if fishing effort remains the same as 1998 (relative for landing of 1998). In general, simulated values were greater than observed values, but it is clear that both curves present similar trend. This overall conclusion is confirmed by Fig. 4, in which simulated and observed total landings are visualized.

Discussion

Information on all non-fish compartments and diet composition is scarce in most South American reservoirs and the case of the Itaipu is not different. In order to overcome this problem, we used the same information for non-fish compartments in both models. In fact, this simplification may be useful because it may allow a better understanding of the fisheries dynamics by standardizing non-fish parameters whereas the input fish species values were changed. Parameter estimates results from Ecopath appear reasonable, especially for fish biomass differences between Itaipu-1 and Itaipu-2.

Resilience of disturbed environments may be evaluated by ecosystem attributes. Input fishing on second model did not change whole results (Table 3). Apparently, ecosystem of Itaipu Reservoir represented by models is an accommodation phase and therefore, models did not detect any trend related to aging. Then, it can be assumed that the reservoir achieved some level of stability, but still far from maturity. This opinion is corroborated by limnological data (Agostinho *et al*., 1999b) and by little fluctuations in the composition of trophic groups (Hahn *et al*., 1998).

Aging in ecosystems was discussed in Lindeman (1942), who ventured to diagram a hypothetical "hydrosere". However, the identification of phases in a reservoir appears to be completely different than in a lake, because reservoirs are formed fast. In addition, opportunistic species pre-adapted to colonize lentic environments, like the exotic *P. squamosissimus* in the Itaipu Reservoir, could control and stabilize ecological succession. Besides, dam operation may also alter equilibrium of communities, which may lead the ecosystem represented by the Itaipu Reservoir to an intermediate level of development.

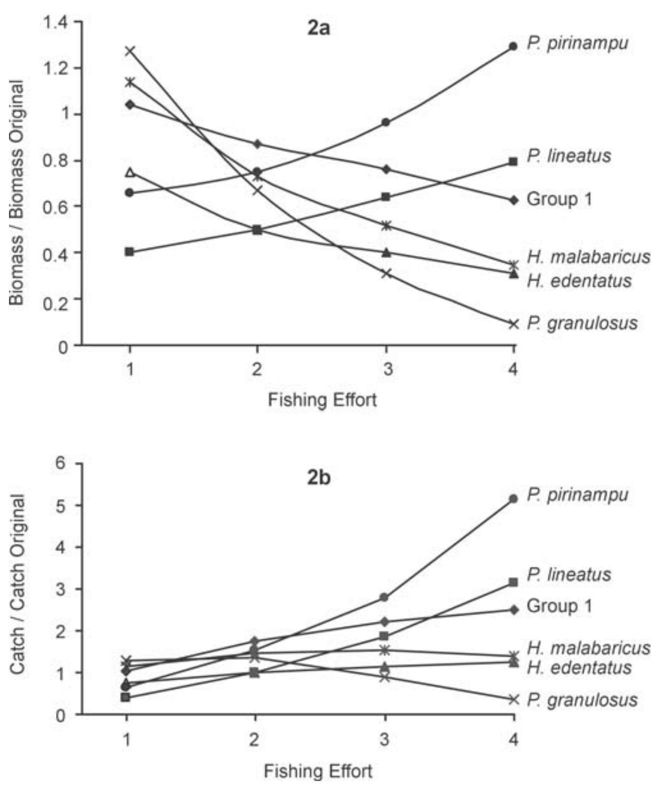

Fig. 2. Relative biomass (2a) and relative catch (2b) of the main species of the Itaipu-2 model, with increasing of fishing effort. Fishing effort = 1 is equivalent to that registered in 1998. This value was multiplied by 2, 3 and 4, in order to get other fisheries scenarios. Simulations made in Ecopath with Ecosim (Subroutine: Run Ecossim, module: Results).

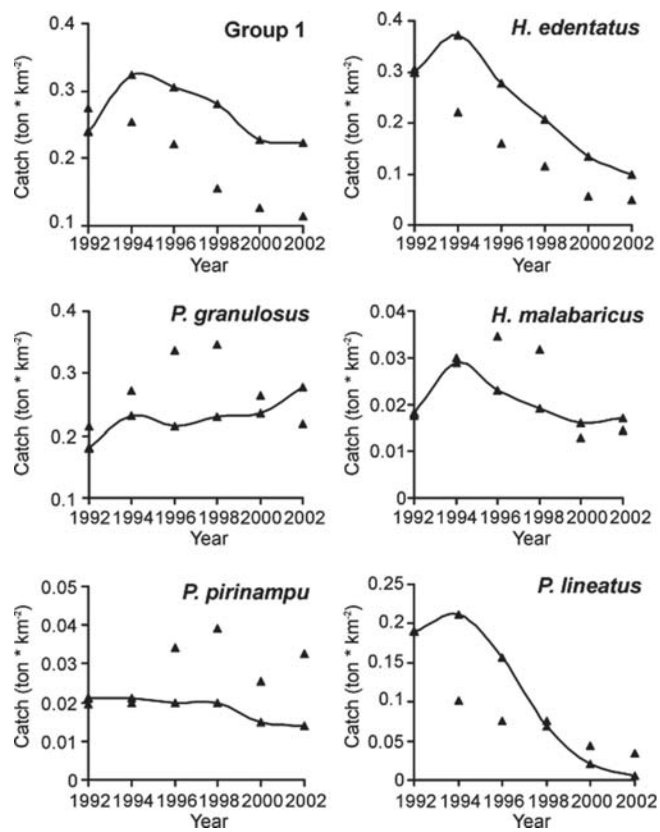

Fig. 3. Simulated catches (solid line) and catch values observed (triangles) for the main species of the Itaipu-2 model, under the same fishing effort of 1998. Simulations made in Ecopath with Ecosim (Subroutine: Run Ecossim, module: Results).

Mean trophic level of the catch (yield) in Itaipu-2 is high (2.8) and gross efficiency (catch/net primary production) is 10 times lower than a Sri Lanka reservoir (Moreau *et al*., 2001). This low efficiency and yield can be attributed to the low number of lacustrine – pre adapted species, long food chains, high number of predatory species and low primary production (Miranda *et al*., 2000, Gomes & Miranda 2001, Gomes *et al*., 2002).

Results obtained in this study show that the Itaipu Reservoir is more near maturity than the Broa Reservoir (Angelini & Petrere, 1996) because it presents higher values of total primary production/ total respiration, Finn cycling index and overhead (Table 3). However, reservoir Ria Formosa lagoonal system is closer to maturity than the Itaipu because it has an important detritus support food chain (Gamito & Erzini, 2005).

Validation is an essential step in modeling procedure and it tests model against an independent set of data (JØrgensen, 1994). Simulation in Itaipu-1 (1983-1987), for five years, resulted in biomass values similar to the ones obtained in Itaipu-2 (1988-1992) (not significant paired *t* test). This enabled us to validate the Ecopath with Ecossim routine and, consequently, to make more comfortable the simulations on Itaipu-2.

Results obtained through simulations are very close to mono-specific stock assessment data for the same species and periods (Agostinho *et al*., 1999a). Thus, apparently, it is possible to increase fishing effort, towards *P. pirinampu* and *P. lineatus* (Fig. 2). Also, *P. pirinampu* biomass shows tendency to increase whereas *P. granulosus* and *H. edentatus* biomasses would be affected and decreased, if fishing effort remains the same (Fig. 3). Alteration in river level, specially the control of floods prompted by dams located upstream from the Itaipu Reservoir appears to be the main cause of these findings (Agostinho *et al*., 2004).

Agostinho *et al.* (1999a) and Okada *et al.* (2005) show that *P. squamosissimus* and *P. maculatus* (Group 1) fisheries are near to maximum sustainable yield. Nevertheless, Group 1 biomass is the most stable (Fig. 3) probably because *P. squamosissimus* is abundant. Differences between simulated and observed data to Group 1 are high because we do not have landing data of *S. marginatus*, which is explored commercially only when other species are lacking and sometimes this species is discarded due to low market price. Moreover, in general, groupings in food webs present more stable results than single species does (Naeem & Li, 1997; Solow & Beet, 1998).

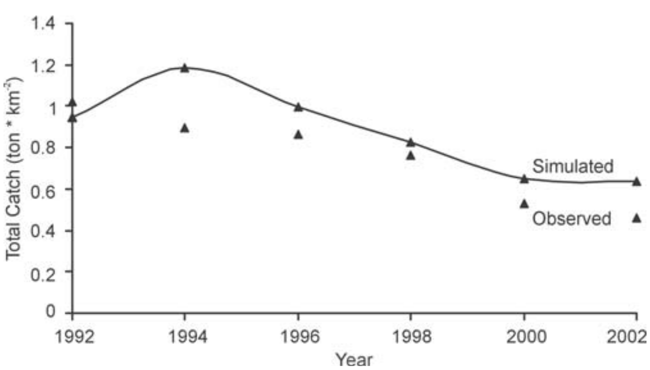

Fig. 4. Simulated Total catch (solid line) and catch values observed (triangles). Simulations performed on Itaipu-2 model, under constant fishing effort (values were close to 1998). Simulations made in Ecopath with Ecosim (Subroutine: Run Ecossim, module: Results).

Simulated trend in catches from Itaipu-2 overestimated observed values (Fig. 4), but with same tendency, showing that model could support and to help stock assessment and fishery management. Even so, this model could be improved with quantitative studies in non-fish compartments (for example, bacterioplankton which is essential to understand recycling) and feeding data of juveniles of top predators that would allow splitting top predators into two boxes (juveniles and adults).

Many authors believe that tropical ecosystems are environments where biotic and abiotic oscillations are annual and sometimes unexpected. But between 1983 and 2003, Itaipu Reservoir appears to get some stability although far from maturity. Itaipu can support fishing activity with increasing fishing effort of some species since, during the spawning period of majority of species, fishery continues prohibited.

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