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Full Length Research Paper

Trophic analysis and fishing simulation of the biggest Amazonian catfish

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Currently, it is unanimous the fact that the ecosystem approach gives important insights to support fisheries stock assessment and management and healthy sustain aquatic ecosystems. This work aims at the quantification of energy flows at várzea (Amazon floodplain) and the simulation of increase in the fishing effort regarding the biggest predators, the catfish, and decrease of flooded forest cover. It was used the Ecopath with Ecosim software to build BAGRES model, which could allow inferences on ecosystem stability. Results showed that: i) BAGRES model has high overhead (69.7%) and Production/Respiration rate very close to 1, showing that this floodplain system is sufficiently mature and capable to support disturbance; ii) Finn's cycling index for BAGRES (14.6%) is high when compared to other worldwide system; iii) increasing the effort of the catch of three species of Brachyplatystoma (catfish) have positive effects on biomass and consequently catch and landing of their main preys; iv) in the simulation of deforestation of Floodplain Forest (with no natural regeneration), all species are prejudiced (no exception), including Brachyplatystoma groups that do not use flooded environment. Therefore, the indirect consequence of the deforestation is more intense over fish stocks than increasing fishing effort. The BAGRES model results have important implications for the current policy-making for inland fishing in Brazil, currently mostly based on "defeso" (fishing restriction season), suggesting the necessity of incorporate the impacts which drive the deforestation in Amazon Floodplain.

Key words: Brachyplatystoma sp; várzea, Amazon floodplain; fisheries; Ecopath with Ecosim.

INTRODUCTION

The ecosystem concept is considered the most important in Ecology because it combines other topics like population, community, flows among components, energy, cycling, predation, resources sustainable management and conservation (Cherret, 1989). Food webs are synonymous of ecosystems and it may be defined as complex adaptive systems (Power and Dietrich, 2002). Mathematical models that describe food webs can be supportive to fishery stock management, since they are complementtary to the stock assessment models, which typically focus on a single target species.

Nonetheless, these traditional models ones have been proven to be insufficient to avoid overexploitation on fishing resources and or their declination due to habitat degradation (Mace, 2001; Hilborn et al., 2003; FAO, 2003).

Ecosystem-based fisheries management (EBFM) is a new approach for fishery management, essentially reversing the order of management priorities to start with the ecosystem rather than the target species, aiming ensure sustainable and healthy aquatic ecosystems (Pikitch et al., 2004).

Although most of scientific articles about EBFM are related to marine system (see for example Heymans et al., 2004), the use of EBFM concepts in freshwater is important because inland fisheries are more vulnerable to environmental changes and it plays an essential role as

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worldwide food security (FAO, 2002).

Fish species represent one of the most important resources along Amazon River in Brazil and it contributes significantly to the local economy, playing a vital role in the local diet as one of the primary sources of protein for the majority of the population. Batista et al. (1998) estimated a daily fish consumption of 550 g per person in riverine communities.

Fishing is also important for the Amazon Basin economy and it has been is focused on larger catfish species that are not consumed by local population. However, they constitute valuable resource and are exported to several countries. Unfortunately, in the last decades, there are emerging signals of overexploitation of some species including catfish (Goulding, 1980; Bayley and Petrere, 1989; Barthem and Goulding, 1997; Petrere et al., 2004; Fabrè et al., 2005).

One thousand three hundred species of fish recorded in Amazon depend, directly or indirectly, on Várzea (Amazon Floodplain) and on the flood pulse (Junk et al., 1989).

During inundation, fish migrate into floodplain forests to feed on fruits, seeds and insects, in an area of superior to 60,000 km^2 in size and which make up the major source of carbon for local fisheries (Araújo-Lima et al., 1998; Araújo- Lima and Goulding, 1997). One of the main trophic characteristics of the Amazon floodplain is the high degree of omnivory, which place some uncertainty concerning the carbon dynamics tracking in this system (Bayley, 1983).

Bearing the above context in mind, the aims of this article are: (i) the quantification food web of the Amazon River including the commercially exploited catfishes species: *Brachyplatystoma rousseauxii* (dourada), *Brachyplatystoma vaillantii* (piramutaba), *Brachyplatystoma filamentosum* (piraíba), *Pseudoplatystoma fasciatum* (surubim) and *Pseudoplatystoma tigrinum* (caparari); (ii) the verification, *via* simulation, of the catfish stocks respond to both fishing pressure increment and the cut of the floodplain forest; (iii) compare the outcomes of the model with the ones previously obtained for the Upper Parana River floodplain (PLANÍCIE model, Angelini and Agostinho 2005a); and (iv) quantify the direct and indirect interactions among groups using the Leontief impact matrix.

Methods

Model

The Ecopath software (Christensen and Pauly, 1993) was employed to build the food web model. Ecopath is a model of mass balance developed by Polovina (1984) with approach of energy flows proposed by Ulanowicz (1986). The basic assumption in these models is that the input to each group is equal to the output (conditions of balance) . Tus, a series of biomass budget equations are determined for each group as:

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

Walters et al. (1997) upgraded the steady-state model in Ecopath, including a routine that provides a framework for management environmental simulation (Ecosim). The resulting budget equations become a system of 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 the 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 the 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.

The model developed for Amazon Floodplain was baptized BAGRES (catfishes in Portuguese). Fishing simulations were carried out for five years multiplying by 2, 3 and 4 the fishing effort of 2001 (last observed year). Deforestation was simulated reaching up 25%, 50%, 75% and finally 100% (no regeneration). In addition, the model assessed ecosystems attributes *sensu* Ulanowicz (1986) and the Leontief impact matrix, which are discussed in detail.

Data Source and Components

The input values for the BAGRES model parameters were obtained from the literature. Flooded forest biomass and production data was quoted in Worbes (1997). Other sources were used: Junk and Piedade (1997) for macrophytes; Putz and Junk (1997) for phytoplankton; Doyle (1991) for periphyton; Bayley (1983) for *Macrobrachium*; Junk and Robertson (1997) for other aquatic invertebrates; Adis (1997) for terrestrial invertebrates and Sipaúba – Tavares, et al. (1994) and Angelini et al. (1996) for zooplankton. Biomass values were estimated to the catfish main species, multiplying landing values from 2001 (MMA, 2002) for Amazonas and Pará States by 5, 7 or 8 as an expert's supposition suggested by Barthem and Goulding (1997). Both catfish and other components data were standardized to the $kg*ha^{-1}$ or $kg*ha^{-1}*year^{-1}$.

Each one of the 14 more abundant species was represented by one compartment (components 9-22 in Table 1), for which PB was estimated using Z parameter (total mortality) and QB using Palomares and Pauly (1998) empirical regression. When B was unknown, EE's values were provided all between 0.9 and 0.99. Data on the Family Gymnotidae and three other components were included to the model (components 23-26) based on their feeding habit (piscivores, detritivores and omnivorous). For these constituents, there were estimated PB and QB from species in the same trophic level.

PB values for catfish species, there were calculated used data from Alonso (2002) for *B. rousseauxii*, Pirker (2001) and Barthem (1990) for *B. vailantii*, Muñoz-Sosa (1996) for *B. filamentosum*, Rufino and Isaac (2000, 1995) and Angelini and Agostinho (2005b) for *P. tigrinum* and *P. fasciatum*. Data on diet composition were obtained from Fabrè et al. (2000), Avila (1999), Araújo-Lima and Goulding (1997), Barthem and Goulding (1997), Leon (1996), Célis-Perdomo (1994), Córdoba (1994) and Maldonado (1974).

For the remaining species, information were obtained in Vieira (2003) and Isaac and Moura (1998) for *Semaprochilodus taeniurus* and *Semaprochilodus insignis*, Angelini (2002) for *Mylossoma aureum*, Angelini and Agostinho (2005b), Ruffino and Isaac (2000) and Isaac and Ruffino (1996) for *Colossoma macropomum*, *Prochilodous nigricans* and *Schyzodum fasciatus*, Angelini and Petrere (1996) for Family Gymnotidae, and Silva-Jr. (1998) for *Triportheus elongatus* and *Hypophtalmus marginatus*.

Table 1. Basic parameters inputs and outputs (in parentheses) from Ecopath of the Bagres model. B: Biomass; PB: Production/Biomass; QB: Consumption/Biomass; EE: Ecotrophic Efficiency; TL: Trophic Level; Flow in kg*ha^{-1}*ano^{-1}, biomass in kg*ha^{-1}

Compartment	B	PB	QB	EE	TL	No. of pathways	Pathways length
Phytoplankton	17.100	205.000		(0.393)	1.0		
Flooded Forest	39060.0	0.100		(0.015)	1.0		
Periphyton	38.000	8.800		(0.183)	1.0		
Macrophytes	17.100	4.000		(0.903)	1.0		
Macrobrachium	3.200	8.000	80.000	(0.316)	2.0	(1)	(1.00)
Terrestrial Inv.	0.210	25.000	250.000	(0.617)	2.0	(2)	(1.00)
Aquatic Inv.	1.300	25.000	250.000	(0.218)	2.0	(4)	(1.00)
Zooplankton	24.200	54.700	273.500	(0.530)	2.1	(2)	(1.00)
B.rousseauxii	11.234	1.310	7.340	(0.094)	3.2	(165)	(3.58)
B.vaillanti	1.972	1.180	7.340	(0.085)	3.2	(142)	(3.73)
B.filamentosum	1.330	0.396	(2.125)	0.505	3.3	(172)	(3.63)
P.tigrinum	1.300	4.000	10.000	(0.199)	3.3	(47)	(2.70)
P.fasciatum	1.900	4.000	12.000	(0.447)	3.3	(79)	(3.08)
S.insignis	5.100	5.100	12.000	(0.994)	2.0	(2)	(1.00)
S.taeniurus	5.100	5.100	12.000	(0.994)	2.0	(2)	(1.00)
M.aureum	4.644	2.230	8.300	(0.964)	2.2	(7)	(1.86)
P.nigricans	5.125	4.570	10.000	(0.944)	2.0	(3)	(1.00)
T.elongatus	3.900	3.400	8.750	(0.924)	2.0	(3)	(1.00)
H.marginatus	4.123	3.400	7.600	(0.976)	3.1	(2)	(2.00)
S.fasciatus	2.800	4.520	16.470	(0.984)	2.0	(2)	(1.00)
C.monoculus	1.300	2.130	(4.735)	0.992	3.1	(16)	(2.38)
C.macropomum	1.150	1.400	8.300	(0.851)	2.1	(3)	(1.67)
Gymnotidae	(4.424)	4.000	10.000	0.990	2.0	(3)	(1.00)
Other detritivores	4.740	1.700	12.000	(0.951)	2.0	(1)	(1.00)
Other piscivores	3.600	1.500	6.200	(0.569)	3.3	(79)	(3.16)
Other omnivores	3.900	1.900	8.300	(0.936)	2.4	(13)	(1.69)
Detritus				(0.683)	1.0		

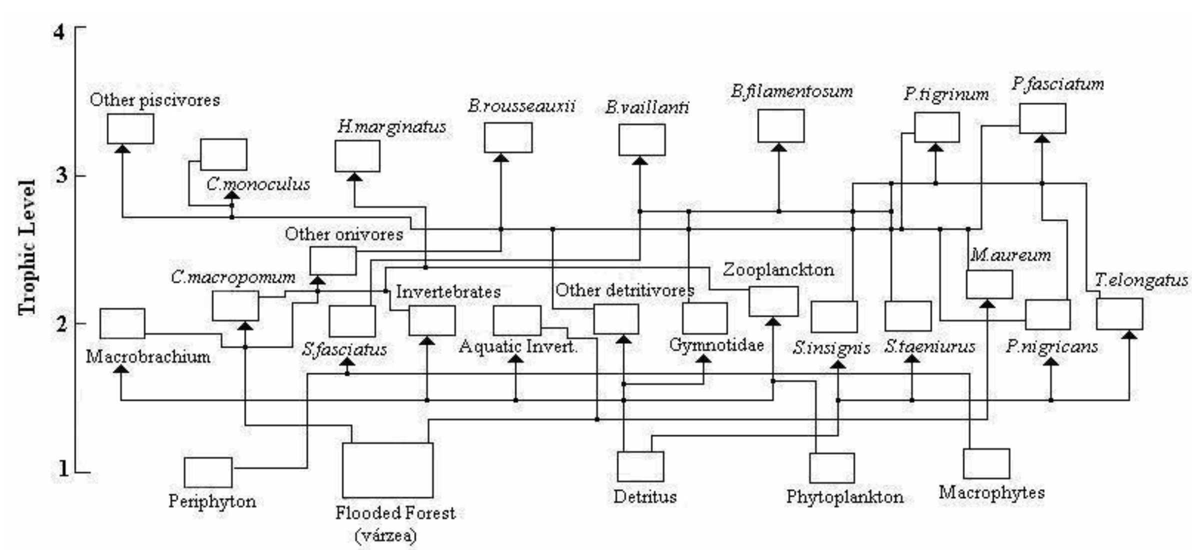

Figure 1. Bagres model: Ecopath model of the *várzea* or Amazon Floodplain. Values of fluxes and biomass of groups are included in Table 1. Just the main fluxes are showed.

Table 2. Diet composition of the compartments of the BAGRES model for Ecopath at Amazon Floodplain.

Prey/Predator	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Phytoplankton			0.10	0.20						0.10	0.05		0.05	0.05					0.10			0.10
Flooded Forest		0.10										0.80						0.90				0.40
Periphyton			0.10										0.05	0.05		0.40			0.10			0.05
Macrophytes			0.10													0.60						0.05
Macrobrachium					0.05	0.05																0.10
Ter. Invertebrates																						0.10
Aqu. Invertebrate												0.10										0.10
Zooplankton				0.10								0.10			1.00			0.10				0.10
B.rousseauxii																						
B.vaillanti																						
B.filamentosum																						
P.tigrinum					0.01	0.01	0.01															
P.fasciatum					0.01	0.01	0.05														0.10	
S.insignis					0.19	0.10	0.19	0.10	0.10								0.20				0.10	
S.taeniurus					0.19	0.10	0.19	0.10	0.10								0.20				0.10	
M.aureum					0.05		0.14		0.10								0.10				0.10	
P.nigricans					0.15	0.20		0.10	0.10												0.10	
T.elongatus					0.07		0.15	0.10	0.05								0.20				0.10	
H.marginatus					0.07	0.05		0.15	0.10												0.10	
S.fasciatus					0.05	0.15		0.10	0.15								0.20					
C.monoculus							0.05	0.05	0.05								0.10					
C.macropomum									0.05													
Gymnotidae					0.10	0.20	0.20	0.10	0.10												0.10	
Other detr.					0.03	0.05		0.10													0.10	
Other piscv.									0.10													
Other omniv.					0.03		0.05	0.10													0.10	
Detritus	1.00	0.90	0.70	0.70						0.90	0.95		0.90	0.90					0.80	1.00		

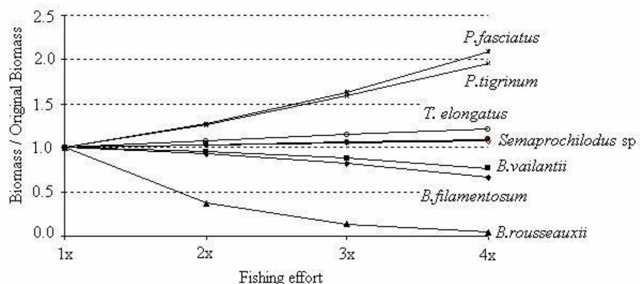

Figure 2. Variations in proportion Biomass/Original Biomass of the main species in the BAGRES model, with fishing effort increasing, calculated by Ecopath with Ecosim. Fishing effort = 1 is equivalent to observed effort in 2001. To increase fishing effort, 2, 3 and 4 multiplies it.

Table 3. Attributes values for the Amazon Floodplain (BAGRES model) and Upper Paraná River Floodplain (PLANÍCIE model). Trends indicate indices behavior in accordance with theory of ecosystem development of Odum (1969). Upper Paraná River Floodplain values from Angelini and Agostinho (2005).

Ecosystem Attributes	*Bagres* (this paper)	*Upper Paraná*	Trends
Primary Production/Respiration	1.65	2.1	diminishing
Primary Production/Biomass	0.199	10.3	diminishing
Finn cycling index (%)	14.5	6.8	increasing
Path length – [Tf / (TEx+TRe)]	3.10	2.7	increasing
Average residence time (TB/Tsaídas)	5.02	0.1	increasing
Flow from detritus	0.6	0.52	increasing
Overhead (%)	69.7	65%	increasing
Ascendência (%)	30.3	35%	diminishing

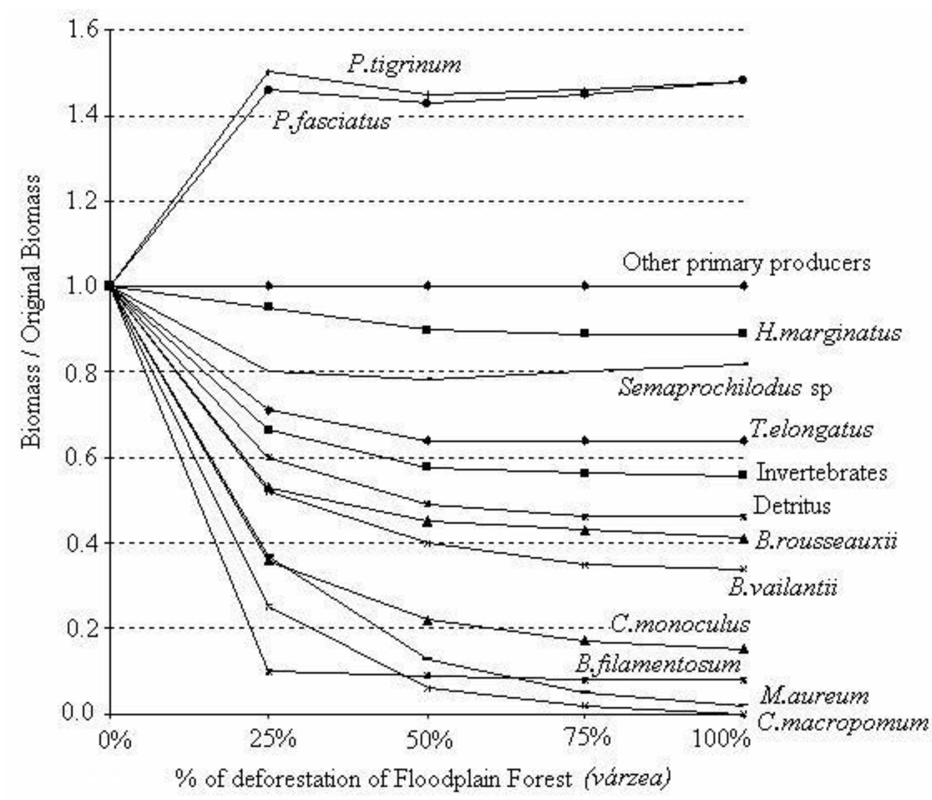

Figure 3. Variations in proportion Biomass/Original Biomass of the main species in the BAGRES model under deforestation of Floodplain Forest (*várzea*) calculated by Ecopath with Ecosim.

RESULTS

Table 1 shows values of the parameters, and the number of input pathways and mean length of pathways for each compartment of BAGRES model. The diet matrix is given on Table 2 and Figure 1 depicts the main fluxes in BAGRES food web.

Table 3 shows a comparison ecosystems attributes of BAGRES model comparing them with PLANÍCIE model (Angelini and Agostinho, 2005a) and also ecosystems development trends *sensu* Odum (1969).

Figure 2 shows the effect of the increasing of the fishing effort effects on most important species. Results are displayed as the changes in proportion between Final Biomass and Initial Biomass, respectively, in 2006 and 2001.

Figure 3 presents an unusual kind of simulation to the Ecopath models, because it modifies primary producer, reducing floodplain forest biomass (component 2). Therefore, the simulation of deforestation was performed in the course of 7 years, showing that all fish species will be threatened, in special *C. macropomum* and *M. aureum,*

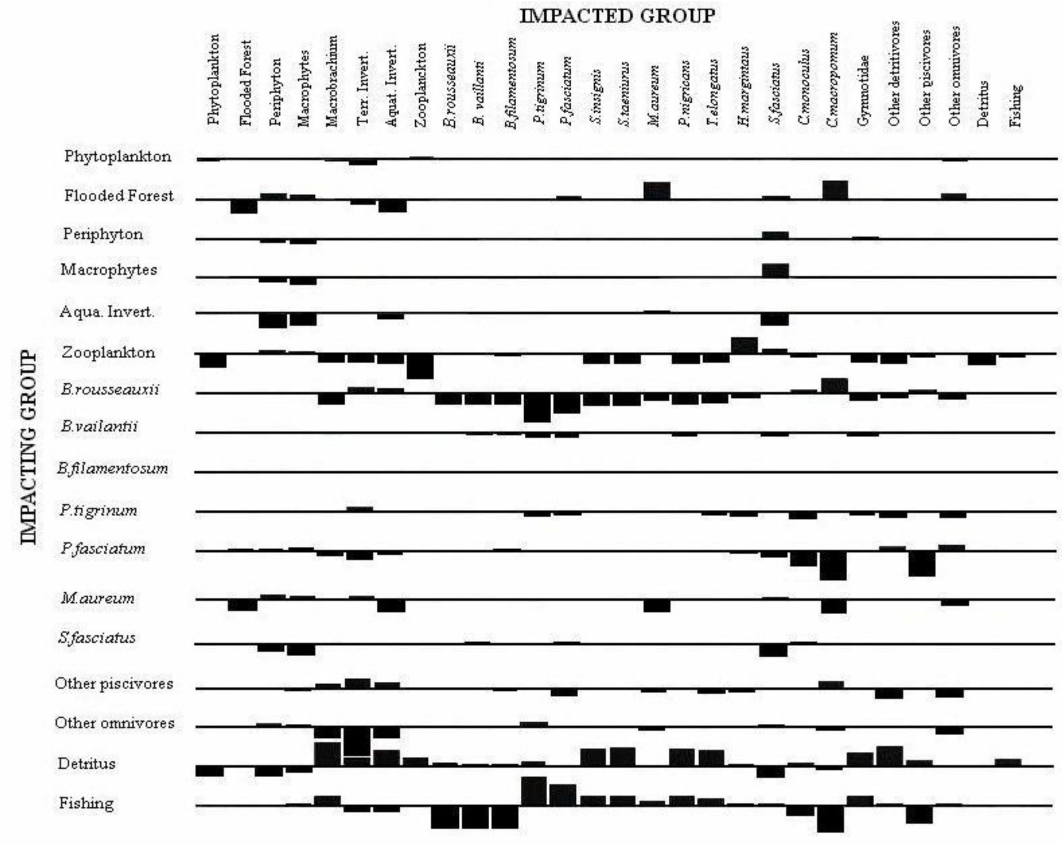

Figure 4. Leontief Impact Matrix (BAGRES model), showing impact positives (bars up) and negatives (bars down) on compartments of columns. Just main impacting groups are showing in the rows.

whose diets are based on fruits and seeds.

Figure 4 depicts Leontief matrix, where the increase of 20% in the biomass of the impacting groups (rows) causes impact direct and indirect on impacted groups (columns). Compartments that cause more alterations on the ecosystem are Detritus, Fishing, *B. rousseauxii*, Zooplankton and Flooded Forest.

DISCUSSION

Simulations showed that three *Brachyplatystoma* components had the highest lengths and number of pathways. Generalist diet of these components (Table 2) seems to have contributed significantly to this result, thus these three catfishes increasing redundancy and resilience. This topic was stressed by Angelini and Agostinho (2005a) which showed length and number of pathways are attributes with high correlation to system's maturity.

High homeostasis was confirmed by other attributes (see Table 3). For instance, the high overhead (69.7%) and Production/Respiration rate very close to 1, indicates that this floodplain system is sufficiently mature and capable to support disturbance. Odum (1969) proposes that a periodic physic perturbation (flood pulse) maintains the system in a intermediate state between mature and "young". However, in the present case, the outputs of the model suggest that Amazon Floodplain is a mature system.

Finn's cycling index for BAGRES (14.6%) was high when compared to other system worldwide (Christensen and Pauly, 1993) corroborating the trends of ecosystem development theory that foresee detritus as a possible main source of energy.

Undoubtedly, BAGRES may be considered more mature when compared with the PLANÍCIE model (Table 3), even considering that the later encompasses nearly 2,000 pathways whereas BAGRES, just 750. This difference may be is partly explained due to the fact that there are many detailed studies on the diet of fishes species from the Upper Paraná River Floodplain (see, for instance, Hahn et al., 1997) whereas this subject is poorly know for the Amazon Floodplain.

However, resilience in BAGRES was higher than PLANÍCIE because floodplain forest (the main source of detritus) strongly influences the Amazon ecosystem and the floodplain forest does not exist anymore along the margins of Upper Paraná River.

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Fishing and removal of Flooded Forest simulations

The increase of the fishing effort on the three *Brachyplatystoma* constituents had positive effects on the biomass and consequently in the landings of their main preys (Figure 2). This agree with the work of Barthem and Goulding (1997), who estimated that *B. rousseauxii* could be consuming more fish than the whole annual landings registered in the Manaus City (13,000 metric tons in 2001).

The increase of the biomass of two *Pseudoplatystoma* groups with increasing fishing effort (Figure 2) may be explained by the reduction in the abundance of their main predator, *Brachyplatystoma* spp. Herein Fabrè et al. (2000) observed that in Upper Amazon River there was an increase in *Pseudoplatystoma* catch after the diminishment of *Brachyplatystoma* spp landings, especially *B. filamentosum* (which was dominant species over 50's years) . This local fact validates our simulation for the basin. In addition, *Pseudoplatystoma* groups could have their landings increased whether the effort became higher.

Figure 3 depicts simulations results from the cut of Flooded Forest (with no natural regeneration). Without exception, all species were jeopardized, including the *Brachyplatystoma* components that do not use (directly) flooded environment. Therefore, indirect consequence regarding deforestation of the *várzea* would be more intense over fishing stocks than increasing the fishing effort.

Conclusion

Amazon Floodplain is a complex environment, which depends on periodic inundation. The main concern about BAGRES model is that if it truly represents the ecosystem. Although, flood pulses have been proven to influence the organisms, other ecological process, such as competetion, predation and the detritus recycling also play relevant rules on structure community and respective food web (William and Martinez, 2000) thus allowing the overall approach employed here, because it is unique in considering all relevant ecological factors on both the organisms and the environment.

Accordingly, the BAGRES model may be regarded as a useful tool for management since it incorporates most the relevant ecological process and, in addition, may also simulating the effect of deforestation in Amazon Floodplain on the aquatic ecosystem. Therefore BAGRES outcomes are reliable and reasonably realistic for the Amazon River system and could readily contribute for the current policy of management inland fisheries in Brazil, mostly based on "defeso" (fishery restriction season).

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