Inter-annual variations in the abundance of young-of-the-year of migratory fishes in the Upper Paraná River floodplain: relations with hydrographic attributes

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(With 4 figures)

Abstract

In this study, we identified and characterized the hydrographic attributes related to the success of recruitment of migratory fishes in the Upper Paraná River floodplain. To achieve our objectives, we analyzed inter-annual variations in the abundance of young-of-the-year (YOY; index of recruitment) of six migratory species and their relations with hydrographic attributes. Recruitment was related to the intensity, duration (in different fluviometrical levels), elasticity, number of pulses, greater uninterrupted overflow and delay of the floods (all obtained using the PULSO software). Collections of fish were conducted in the period between January 1987 and November 2007 in distinct environments (river channels, secondary channels and connected and disconnected floodplain lakes) distributed along three subsystems (Paraná, Baía and Ivinheima). Relations between recruitment and the attributes of interest were determined through analysis of covariance. In the studied period, the highest abundances of YOY were registered in 2007, followed by 1992, 1993, 2005 and 1988. The abundance of YOY was positively correlated with an intensity of high water levels (potamophase) and the duration of potamophase 1 and negatively with the duration of low water levels (limnophase) and a delay of flood. Higher hydrometric levels (540 and 610 cm for Paraná and 325 and 450 cm for Ivinheima) and greatest uninterrupted overflow presented different relations (significant interactions) among subsystems, but all with positive effects on recruitment. Results evidenced that recruitment responded better when floods started in January with potamophase intensities above 610 cm and water levels above 450 cm over a period of 50 days and repeated every two years (or > 610 cm for 38 days and repeated every two or three years). Therefore, artificial control of the floods at intervals of two or three years by manipulating the discharge of dams located upstream from the floodplain in a way that promotes potamophases with the potential to ensure recruitment of migratory species may become an important tool for conservation of migratory fish species in the floodplain.

Keywords: recruitment, discharge regulation, flood, Ivinheima River, Paraná River.

Variações interanuais na abundância de jovens-do-ano de peixes migradores da planície de inundação do Alto Rio Paraná: relação com atributos hidrográficos

Resumo

Este estudo buscou identificar e caracterizar os atributos hidrográficos relacionados ao sucesso do recrutamento de peixes migradores na planície de inundação do Alto Rio Paraná. Para isso, foram analisadas as variações interanuais na abundância de jovens do ano (indexador do recrutamento) de seis espécies de peixes migradores e sua relação com os atributos hidrográficos intensidade, duração (em diferentes níveis fluviométricos), elasticidade, número de pulsos, maior cheia contínua e atraso das cheias. As capturas foram realizadas no período de janeiro de 1987 a novembro de 2007 em diferentes ambientes (canal do rio, canais secundários e lagoas abertas e fechadas) distribuídos em três subsistemas (Paraná, Baía e Ivinheima). A relação entre recrutamento e os atributos foi avaliada através de análises de covariância. No período estudado, a maior abundância de jovens-do-ano ocorreu em 2007, seguida de 1992, 1993, 2005 e 1988, sendo incipiente nos demais anos. A abundância de jovens do ano relacionou-se positivamente com a intensidade de potamofase e duração de potamofase 1 e negativamente com a duração do período de águas baixas (limnofase) e atraso no início das cheias. Níveis hidrométricos mais elevados (540 e 610 cm no Rio Paraná e 325 e 400 cm no Rio Ivinheima) e as maiores cheias contínuas apresentaram relações distintas para os subsistemas (interação significativa), com respostas positivas no recrutamento. Os resultados permitem evidenciar que a melhor resposta no recrutamento foi verificada na cheia iniciada em janeiro, com intensidade de potamofase superior a 610 cm, com níveis superiores a 450 cm por mais de 50 dias e repetida a cada dois anos (ou >610 cm durante 38 dias e repetida a cada dois ou três anos). Diante disso, o controle artificial das cheias pela manipulação de vazão das hidrelétricas a montante, que permita a ocorrência de potamofases com potencial para assegurar sucesso no recrutamento dos peixes migradores, a cada dois ou três anos, pode tornar-se uma importante ferramenta para a preservação das espécies migradoras na planície.

Palavras-chave: recrutamento, regulação da vazão, cheia, Rio Ivinheima, Rio Paraná.

1. Introduction

Migratory fish species of the Neotropical region are characterized by their large size, wide home range and close dependence of the processes linked to recruitment (migration, spawning and initial development) on the flood regime. These features lead migratory fish to be particularly vulnerable to habitat fragmentation and to control of the seasonal flood regime, both of which result from any damming (Agostinho et al., 2005; Agostinho et al., 2008). Due to their high commercial value, any impact of dams on migratory fish stocks is worrying, with implications for diversity and social groups that depend on the fisheries to maintain their livelihoods (Okada et al., 2005).

The ichthyofauna of the Paraná River is composed of 310 catalogued species (Langeani et al., 2007). Among these species, 31 can undergo long migrations for spawning (>100 km; Agostinho et al., 2007a). Six of these migratory species were already classified as threatened (*Brycon nattereri* (Günther, 1864)*, Salminus brasiliensis* (Cuvier, 1816)*, Steindachneridion scripta* (Miranda-Ribeiro, 1918)*, Zungaro jahu* (Ihering, 1898), *Pseudopimelodus mangurus* (Valenciennes, 1835) and *Rhinelepis aspera* Spix and Agassiz, 1829), two as near threatened (*Salminus hilarii* (Valenciennes, 1850) and *Pseudoplatystoma corruscans* (Spix and Agassiz, 1829)) and one as endangered (*Brycon orbignyanus* (Valenciennes, 1850); high risk of extinction) (Abilhoa and Duboc, 2004).

In the Upper Paraná River, migratory species require at least three types of habitats to complete their life cycles (Suzuki et al., 2004; Agostinho et al., 2007b; Pelicice and Agostinho, 2008). They need a spawning habitat (upper stretch of tributaries or of the Paraná River), a habitat of initial development ("várzeas", in lower stretches of tributaries and margins of the Paraná River), and habitats for growth and feeding (the entire basin). In addition to these requirements, the success of recruitment of migratory fish is largely regulated by the timing, duration and intensity of floods. This is clear if we consider the synchronism between the hydrological phases and the events of the biological cycle, such as gonad maturation, migration, spawning and initial development of larvae and fry (Agostinho et al., 1993; Gomes and Agostinho, 1997; Bailly et al., 2008). Increased river levels are related to migration and spawning (Vazzoler, 1996), and flooded areas augment the availability of shelter and food in the initial stages of development, positively affecting recruitment to adult stocks (Gomes and Agostinho, 1997; Agostinho et al., 2004a; Bailly et al., 2008).

The existence of more than 70 large reservoirs (area > 100 ha) leads to a notable level of regulation of the discharge of the Upper Paraná River, affecting the connectivity between the Paraná River channel and the remnant of the floodplain located below Porto Primavera Dam (Souza Filho et al., 2004a; Fernandes et al., 2009). However, the manipulation of the released discharges of the dams upstream has potential to favor recruitment, especially for long distance migratory fish (Agostinho et al., 2004b; 2005). According to Pelicice et al. (2005), the operation of Porto Primavera, which does regulate water discharges and is located immediately upstream from the plain, may constitute an important management action to restore stocks of migratory species.

In this paper we investigated the hydrological attributes related to the success of recruitment of migratory fish. Considering the hypothesis that juvenile recruitment of migratory fish is highly dependent on the attributes of the hydrologic cycle, we tried to answer the following questions: When should a flood begin in order to maximize recruitment? What water level of the river favors high levels of recruitment? How long should a flood last to guarantee the success of recruitment? To achieve these objectives, we analyzed inter-annual variations in the relative abundances of young-of-the-year (YOY) of migratory species and their relation to hydrometric attributes of the Paraná and Ivinheima rivers, located in the Upper Paraná River basin.

2. Study Area

The studied area is located between the mouths of the Paranapanema and Ivinheima rivers (22° 40'-22° 50' S and 53° 10'-53° 40' W), including the main channel of the Paraná, Baía and Ivinheima Rivers, lakes connected to or disconnected from these rivers, secondary channels and the adjacent floodplain (Figure 1). Originally, the river-floodplain system of the Upper Paraná was 480 km long, between the municipalities of Três Lagoas (Mato Grosso do Sul State) and Guaíra (Paraná State). However, half of this area was subtracted by the filling of Sergio Motta Reservoir (locally named Porto Primavera). The first filling phase of this reservoir was concluded in December 1998 (level 253 m) and the second in March 2001 (level 257 m). The first three turbines started operation in March 1999 and the last in October 2003.

Today, the river-floodplain system of the Upper Paraná River is 230 km in length, between Porto Primavera Dam and the Itaipu Reservoir, representing the last lotic stretch of the Paraná River exclusively inside Brazilian territory. According to Souza-Filho (2009), the floodplain is cut by active fluvial channels (Baía River, Curutuba Channel and Ivinheima River) and by sub-active channels, where water flows during floods. In addition, there is a considerable set of floodplain lakes, streams and low areas

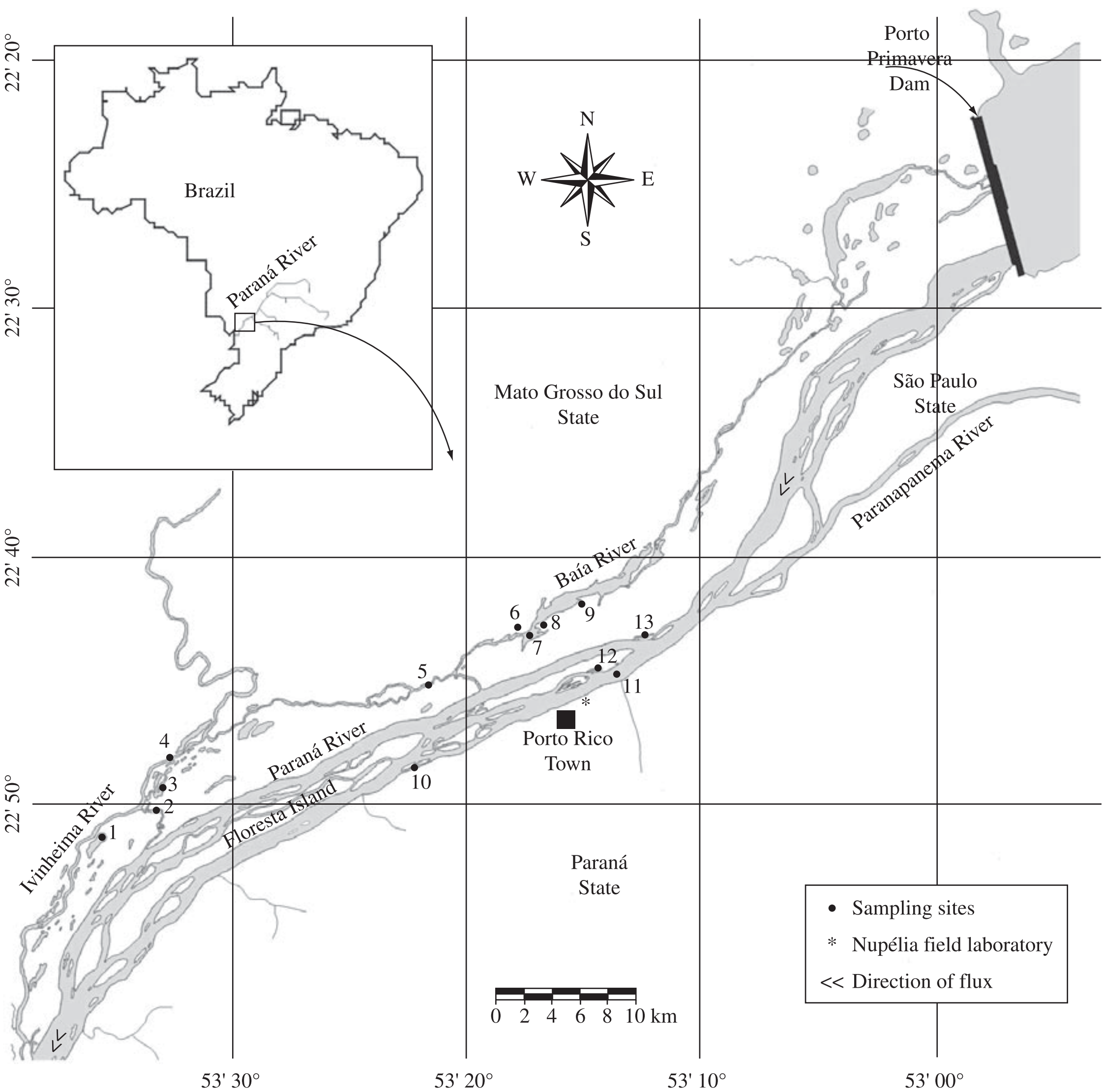

Figure 1. Sampling sites in the Upper Paraná River floodplain: Ivinheima subsystems (1- Ventura Lake, 2- Ipoitã Channel, 3- Patos Lake, 4- Ivinheima River); Baía subsystems (5- Curutuba Channel, 6- Guaraná Lake, 7- Baía River, 8- Fechada Lake, 9- Pousada das Garças Lake); and Paraná subsystems (10- Cortado Channel, 11- Paraná River, 12- Ressaco do Pau Véio (old channel), 13: Garças Lake).

subject to flooding (inundation basin), intermediate areas (deposits of crevasse splay) and higher areas (paleobars, natural levees).

Parallel to the Paraná River and its floodplain flow the Baía River and the lower stretch of the Ivinheima, which are linked by several channels that facilitate exchange of material and allow floods to influence both in different degrees (Arenas-Ibarras, 2008). Floods of the Paraná or Ivinheima Rivers, or a combination of both, initially affect the part of the plain where the Curutuba Channel and the Ivinheima River meet and, later, the entire floodplain (Souza Filho, 2009).

3. Material and Methods

Fish samplings were conducted from January 1987 to November 2007 in three phases (January 1987 to September 1988; March 1992 to December 1994; and February 2000 to November 2007). Samplings took place monthly in 1987-1988 and in 1992-1993; every two months in 1994; and every three months in the last period (2000-2007). Several environments (river channels, secondary channels and connected and disconnected floodplain lakes) distributed in three subsystems (Baía, Ivinheima and Paraná Rivers) that present crescent levels of influence from dams upstream (Figure 1) were sampled. We used gillnets of different mesh sizes to capture fish. Nets were set for 24 hours at each site. From every individual, we measured standard length (Ls) and total weight (Wt).

In this study, young-of-the-year (YOY) were the individuals with lengths smaller than those estimated for one year of age, obtained using growth equations published in the literature (Fenerich et al., 1975; Barbieri et al., 2001; Dei Tos, 2002; Mateus and Petrere Jr., 2004; Araya et al., 2005). Due to the low number of growth studies and the low abundance of some species, we only considered *Prochilodus lineatus* (Valenciennes, 1836), *Leporinus obtusidens* (Valenciennes, 1836), *Pimelodus maculatus* La Cepède, 1803, *Pseudoplatystoma corruscans* (Spix and Agassiz, 1829), *Pterodoras granulosus* (Valenciennes, 1821) and *Salminus brasiliensis* (Cuvier, 1816) in the analysis.

Water levels of the rivers were supplied by the Itaipu Binacional and the "Agência Nacional das Águas" (HidroWeb – National Agency of Water – ANA). Data for the Paraná River were gathered in Porto São José station, whereas those for the Ivinheima were collected in Porto Sumeca station. For the Baía River, we used the water level from the Paraná River because these two rivers flow near each other and parallel, therefore exhibiting very similar variations.

Hydrographic attributes were analyzed using the PULSO software (Neiff and Neiff, 2003), considering only the period between October and May, when floods occur, and, consequently, migratory fish spawn in the region (Agostinho et al., 2004a).

We calculated all attributes using the hydrometric (threshold) level of 450 cm for the Paraná and 275 cm for the Ivinheima Rivers because these correspond to the beginning levels of floods (potamophase) in each subsystem (Comunello et al., 2003), except for durations of potamophases 2 and 3, for which higher levels were considered (see description to follow). Attributes considered were:

- Intensity of potamophase: maximum river level verified in the period;
- Duration of potamophase 1: number of days in which the system was above the threshold levels of 450 cm for the Paraná and 275 cm for the Ivinheima in the period;
- Duration of potamophase 2: number of days in which the system was above the threshold levels of 540 cm for the Paraná and 325 cm for the Ivinheima. These levels represent the average between the stage that covers fluvial bars and the lower limit of the stages that overpass higher levees (Arenas-Ibarras, 2008);
- Duration of potamophase 3: number of days in which the system was above the threshold levels of 610 cm for the Paraná and 400 cm for the Ivinheima. These levels represent overall plain flooding.
- Duration of limnophase: number of days in which the system was below the threshold level established;
- Elasticity: ratio between the intensity of potamophase and intensity of limnophase in the period;
- Number of pulses: number of complete pulses; cycle of a potamophase and a limnophase or vice-versa in the period;
- Greatest uninterrupted overflow: greatest interval of days of uninterrupted flooding in the period; and
- Delay of flood: number of fifteen-day periods after October 1 for which the flood was delayed. For example, a flood that began on December 10 received a flood delay value of five.

Abundances of the fish captured with gillnets were indexed by the capture per unit effort (CPUE; individuals/1000 m^2 of gill nets in 24 hours). For the analysis of abundances, we considered YOY the individuals captured between January and September. We selected this criterion because these individuals are juveniles resulting from spawning that occurred between October and February-March and are already large enough to be captured in gillnets.

To evaluate the relations between the abundances (CPUE) of YOY and the attributes of the flood for each subsystem, we conducted analysis of covariance (ANCOVA). When parallelism was not met (significant interaction), we adjusted separate slope models. Catch of YOY was the dependent variable, flood attributes the covariates and subsystems the categorical variable. The standardized slopes of the ANCOVAs served as indicators of the type (positive or negative) and magnitude of relations with hydrographic attributes that were significantly related to the abundance of YOY.

4. Results

Seasonal fluctuations in the hydrological cycle of the Paraná River during the studied period indicated that floods occurred mainly in January, February and March. In general, floods were discontinuous, except in the cycle of 2006-2007 (Figure 2a). For the Ivinheima River, the water level presented dynamics independent of the Paraná, as seen in the flood of the 2000-2001 cycle, a drought period in which the water of the Paraná River did not overflow (Figure 2b).

We observed wide inter-annual variations in the hydrometric attributes between January 1987 and May

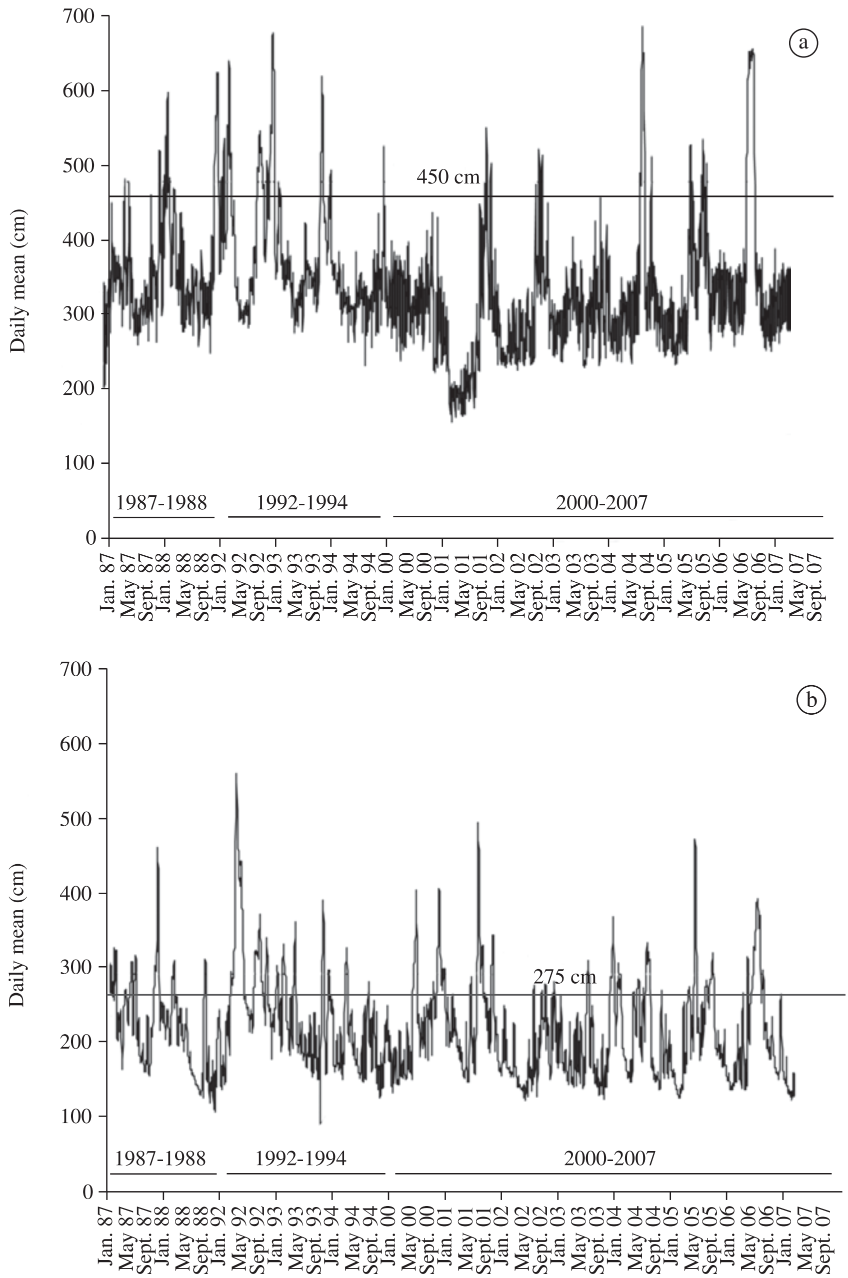

Figure 2. Mean daily water levels of the a) Paraná and b) Ivinheima rivers during the studied period. Dashed lines represent the values from which the rivers overflow onto the adjacent plain.

Table 1. Hydrographic attributes for the Paraná and Ivinheima Rivers during the studied period. Numbers correspond to the years of the hydrological cycle (GUO: greatest uninterrupted overflow).

Hydrographic attributes	86-87	87-88	91-92	92-93	93-94	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07
Paraná River													
Intensity of potamophase	460	584	628	667	605	507	414	532	504	434	676	516	645
Duration of potamophase 1*	2	40	66	92	29	4	0	12	10	0	33	21	57
Duration of potamophase 2**	0	7	26	22	9	0	0	0	0	0	20	0	50
Duration of potamophase 3***	0	0	4	16	0	0	0	0	0	0	14	0	38
Duration of limnophase	241	203	177	151	214	239	242	231	233	243	210	222	186
Elasticity	2.74	2.53	2.65	2.34	2.22	2.29	2.20	4.16	2.57	2.23	3.36	2.43	2.95
Number of pulses	1	4	4	3	2	1	0	2	3	0	2	5	1
GUO	2	19	29	47	24	4	0	9	8	0	29	9	57
Time (beginning of flood)	23 May	12 Jan.	26 Jan.	12 Nov.	18 Jan.	24 Mar.	-	25 Feb.	30 Jan.	-	15 Jan.	21 Dec.	12 Jan.
Delay of flood	16	7	8	3	8	12	-	10	8	-	8	6	7
Ivinheima River													
Intensity of potamophase	298	444	550	348	367	215	385	478	251	296	306	455	369
Duration of potamophase 1*	17	24	39	52	13	0	23	49	0	12	23	22	56
Duration of potamophase 2**	0	13	30	7	8	0	12	15	0	0	0	10	32
Duration of potamophase 3***	0	7	25	0	0	0	0	10	0	0	0	6	0
Duration of limnophase	226	219	204	191	230	243	220	194	243	231	220	221	187
Elasticity	3.77	3.31	5.79	2.49	7.81	2.71	2.78	4.13	3.14	3.61	3.22	3.86	3.93
Number of pulses	4	3	2	3	1	0	2	3	0	2	1	2	2
GUO	11	21	36	30	13	0	22	21	0	7	23	14	51
Time (beginning of flood)	3 Feb.	8 Nov.	10 Oct.	1 Oct.	21 Dec.	-	18 Feb.	16 Nov.	-	14 Dec.	18 Jan.	14 Dec.	10 Dec.
Delay of flood	9	3	1	1	6	-	10	4	-	5	8	5	5

(* considering the levels of 450 cm for the Paraná and 275 cm for the Ivinheima); (** considering the levels of 540 cm for the Paraná and 325 cm for the Ivinheima); and (*** considering the levels of 610 cm for the Paraná and 400 cm for the Ivinheima).

2007. This was clear for the intensity (greatest value of the river level registered in the period) and duration of potamophases. Higher potamophase intensities (above 610 cm) were registered in 1992, 1993, 2005 and 2007. Potamophases that lasted at least 50 days at the 450 cm level occurred in the 1992-1993 and 2006-2007 periods (Paraná). In addition, we noticed that inundations, in general, started earlier in the Ivinheima River (Table 1).

In the studied period, the highest value of YOY capture per unit effort (CPUE) occurred in 2007, followed by 1992, 1993, 2005 and 1988. *Prochilodus lineatus, Leporinus obtusidens* and *Pseudoplatystoma corruscans* were the species with high abundances of YOY (Figure 3). *Prochilodus lineatus* were abundant in 1992, 1993 and 2007; *L. obtusidens* in 1992 and 1993; and *P. corruscans* in 2007. In 2007, *Pterodoras granulosus* presented its highest abundance. Among the considered species, *Salminus brasiliensis* presented lower YOY CPUE in all years. The Ivinheima subsystem contributed higher captures in the years 2007, 1992 and 2005, whereas the Paraná showed higher CPUE in 1993 and the Baía in 1987 and 1988.

Results of the ANCOVA indicated that the CPUE of YOY was positively (positive slopes in Table 2) related to the intensity of potamophase (Figure 4a) and duration of potamophase 1 (Figure 4b) and negatively related (negative slopes in Table 2) to the duration of the limnophase (Figure 4e) and flood delay (Figure 4i).

Due to a significant interaction, separate slope models indicated that, in the three subsystems, there were positive relations with different magnitudes between the CPUE of YOY and duration of potamophase 2 (Figure 4c), duration of potamophase 3 (Figure 4d) and greatest uninterrupted overflow (Figure 4h). The capture of young was not related to the elasticity and number of pulses (Figures 4f, 4g). Standardized slopes allowed the comparison of the magnitudes of the relations. Considering this, the most important variables were greatest uninterrupted overflow and duration of potamophase 2 for the Ivinheima River (b = 0.67 and 0.58, respectively; Table 2). In addition, the intensity of potamophase (b = 0.48; Table 2) and duration of potamophase 1 (b = 0.42; Table 2) were important for all subsystems.

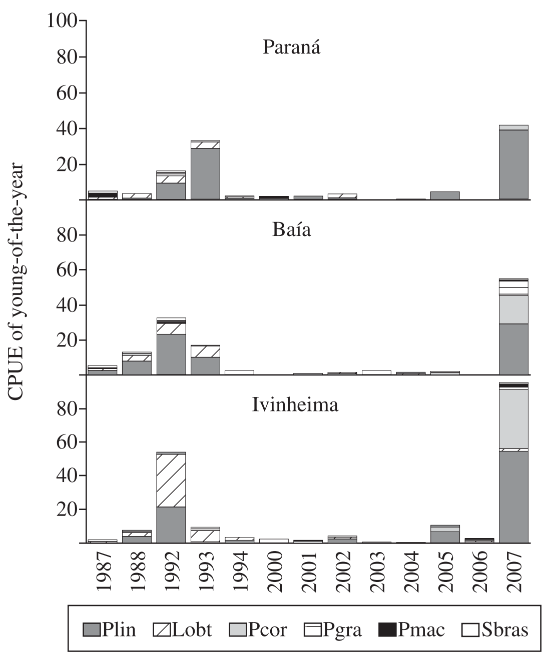

Figure 3. Abundance (capture per unit effort – CPUE) of young-of-the-year of five migratory fish species captured in the Upper Paraná River floodplain in the different years (1987-2007) and subsystems (Paraná, Baía and Ivinheima). Plin = *P. lineatus*; Lobt = *L. obtusidens*; Pcor = *P. corruscans*; Pgra = *P. granulosus*; Pmac = *P. maculatus*; Sbra = *S. brasiliensis.*

5. Discussion

The 350 cm level measured at the Porto São José Station has been used to define the limit between potamophase (connectivity between the river channel and the plain) and limnophase (absence of connectivity) (Arenas-Ibarras, 2008) or to define the flood period (Thomaz et al., 2004; Agostinho et al., 2004b) in the Upper Paraná River floodplain. At this level, the entrance of water into the plain is due to elevation of groundwater, and only the lakes connected to the main river channel are influenced by the Paraná River (Rocha, 2002; Souza Filho, 2009). However, a great number of eggs and larvae or juveniles only reach the floodable area of the plain if there is overflow of the river or lakes. We judged floods as beginning when the Paraná River level reached 450 cm and the Ivinheima level reached 275 cm, as proposed by Comunello et al. (2003). These levels, with some variations, bring effective inundation to the lower parts of the plain (Curutuba/Ivinheima area) (Rocha, 2002; Comunello et al., 2003; Souza Filho et al., 2004b; Souza Filho, 2009).

At the level of 450 cm in the Paraná River, there was increased abundance of YOY in periods with duration of potamophase greater than 50 days, mean abundances between 30 and 40 days and low abundances below these values. However, these figures did not correspond to consecutive days of floods because we noticed a varied number of pulses in these periods. However, the number of pulses did not significantly influence recruitment. Abundance of YOY was also positively related to the intensity of potamophase. Higher values of recruitment were registered in 1992, 1993, 2005 and 2007, when the river level reached values above 610 cm in the Paraná River and 340 cm in the Ivinheima. These levels are related to the flooding of the floodplain in areas with intermediate elevations (Souza Filho, 2009). These findings

Table 2. Results of the analysis of covariance showing the relations between capture per unit effort of young-of-the-year of migratory species and the hydrographic attributes ($p < 0.05$ represents significant relation). DP2 = duration of potamophase 2; DP3 = duration of potamophase 3; GUO = greatest uninterrupted overflow.

Factors	MS	F	P	Standardized slopes
Intensity of potamophase	21237.98	23.97	<0.0001	0.48
Subsystem	34.02	0.04	0.96	-
Duration of potamophase 1	21884.80	24.46	<0.0001	0.42
Subsystem	301.37	0.34	0.71	-
DP2 * Subsystem	5675.79	7.86	<0.001	-
Paraná	-	-	<0.01	0.23
Baía	-	-	<0.001	0.29
Ivinheima	-	-	<0.0001	0.58
DP3 * Subsystem	3034.18	3.63	0.03	-
Paraná	-	-	<0.01	0.22
Baía	-	-	0.03	0.16
Ivinheima	-	-	<0.0001	0.38
Duration of limnophase	21893.18	24.47	<0.0001	–0.42
Subsystem	2034.49	2.27	0.10	-
Elasticity	295.5108	0.30	0.58	-
Subsystem	767.3146	0.785	0.46	-
Number of pulses	140.902	0.14	0.71	-
Subsystem	1383.677	1.38	0.26	-
Flood delay	10166.26	9.77	<0.01	–0.27
Subsystem	564.74	0.54	0.58	-
GUO * Subsystem	4940.89	6.20	<0.01	-
Paraná	-	-	<0.01	0.28
Baía	-	-	<0.01	0.24
Ivinheima	-	-	<0.0001	0.67

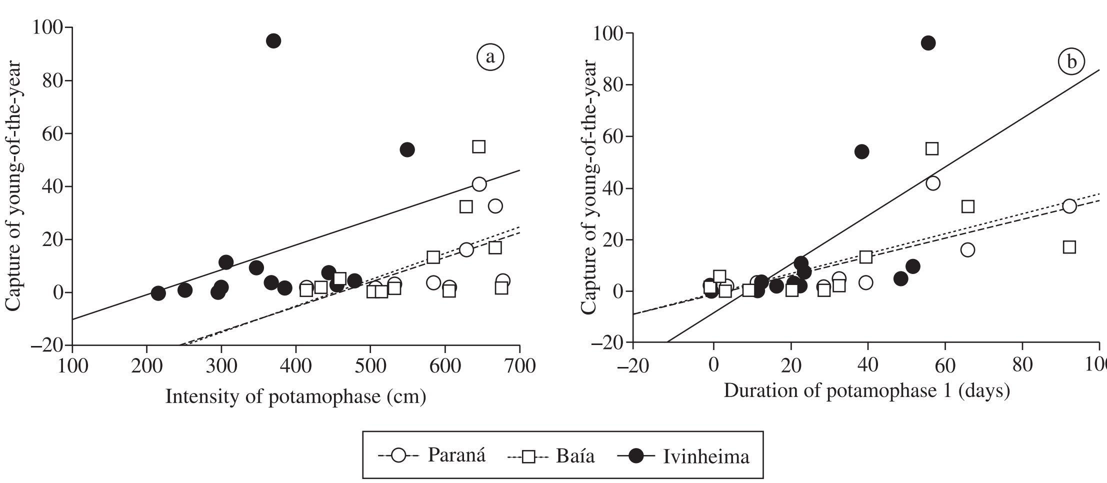

Figure 4. Relationships between abundance of young-of-the-year and hydrographic attributes in the three subsystems.

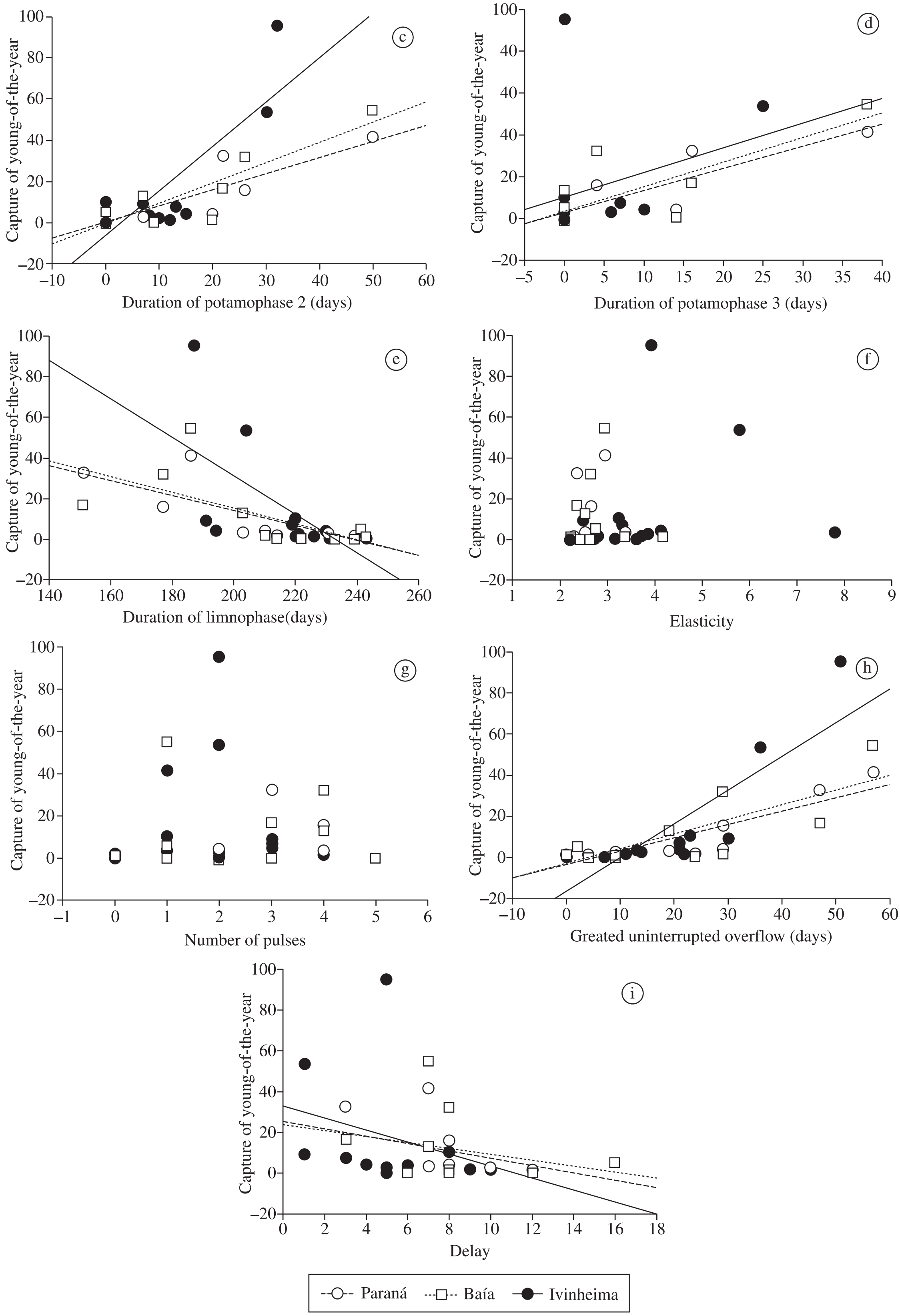

Figure 4 (continued). Relationships between abundance of young-of-the-year and hydrographic attributes in the three sub-systems.

reveal the importance of evaluating the relation between recruitment of YOY and duration of potamophases considering the greatest uninterrupted overflow and also the other two levels as thresholds (540 cm and 610 cm for the Paraná; 320 cm and 400 cm for the Ivinheima). Interactions were significant for these three variables because levels of the Paraná River affect levels of the other subsystems. The abundance of YOY presented significant relationships with these three variables in the distinct subsystems. However, these relations were weaker than those obtained for the duration of potamophase 1, except for the Ivinheima. Floods originated by the Paraná and Ivinheima, or a combination of both initially affect the Ivinheima subsystem (Souza-Filho, 2009). For instance, when the level of the Paraná reaches 610 cm, the inundation zone of the Ivinheima River is completed flooded.

In the Upper Paraná, most of the migratory species spawn between October and January (Agostinho et al., 2004a; Suzuki et al., 2004), and the flood is an important cue for migration and spawning (Godoy, 1975; Vazzoler, 1996). Most of the floods in the Upper Paraná River may begin in this period (Thomaz et al., 2004). In the years when higher recruitments occurred, in general, floods in the Ivinheima started earlier (until the end of December) than floods of the Paraná (until the end of January). Delayed floods, which began in the third week of February, were not effective for recruitment.

In the studied stretch, the Ivinheima River is the most important tributary for reproduction of migratory fish (Vazzoler, 1996), which suggests that most of the juveniles captured in the area dispersed from this river. The Dourados, Brilhante and Vacaria Rivers, which form the Ivinheima, have important spawning habitats and several marginal lagoons in the lower stretches of the basin (Agostinho et al., 2001; Nakatani et al., 2004; Sanches et al., 2006). These features of the regional landscape indicate the important role of these rivers as nurseries for several species. These findings reveal that the initial development may occur in the Ivinheima River basin and that the Paraná River floodplain is fundamental to the growth of juveniles. Floods restricted to the Ivinheima River, as verified in 2002, do not guarantee massive recruitment in the same way as those floods that encompass both subsystems. Regular floods (Paraná River levels around 400 cm) do not relevantly affect the "várzea" in the lower stretch of the Ivinheima River. However, when the river level of the Paraná reaches 600 cm, it strongly influences that region, which is entirely flooded (Rocha, 2002). Higher abundances of YOY in the Ivinheima subsystems, allied to high densities of eggs and larvae drifting reported by Reynalte-Tataje (2007), are in concordance with the importance of the Ivinheima as a spawning area.

The remaining stretch of the Upper Paraná River floodplain includes other tributaries that serve as spawning habitats for migratory species (Baumgartner et al., 2004; Nakatani et al., 2004; Suzuki et al., 2004), such as the Amambai and Iguatemi Rivers in the right (West) margin and the Ivaí and Piquiri Rivers in the left (East) margin. All of these rivers are still unregulated by dams, and they present areas for spawning and initial development of migratory species in spite of some other impacts related to the use of the landscape, such as agriculture and ranching (Agostinho et al., 2004b). Because floods in these rivers are due to rains in their headwaters, we can suppose that the conditions needed for spawning of most migratory species are still preserved.

However, spawning in these rivers does not ensure effective recruitment. Studies of the density of ichthyoplankton conducted in the sub-basin of the Ivinheima River between October 2002 and March 2006 demonstrated the occurrence of larvae of migratory fish in all reproductive periods (Reynalte-Tataje, 2007). Among the captured species, the most abundant were *P. lineatus, P. corruscans, S. brasiliensis, B. orbignyanus* and *Rhaphiodon vulpinus*. Nevertheless, captures of YOY of these species during the period were relevant only in 2005 and 2007, when we registered higher values of intensity and duration of potamophase in the Paraná River. In the flood cycle of 2002-2003, when floods were short and discontinuous, larvae densities were high (Reynalte-Tataje, 2007), and the capture of juvenile (<5 cm) *P. lineatus* and *L. obtusidens* in floodplain lakes with seining nets occurred in March 2003 (unpublished data). In addition, these juveniles were not captured in the other months, indicating a failure in recruitment, regardless of the occurrence of spawning and the presence of juveniles in some floodplain lakes. Therefore, for migratory fish, the success of spawning and the presence of larvae and juveniles in temporary lakes do not necessarily assure recruitment. To be certain about recruitment, monitoring of juveniles until they become adults is necessary. Low recruitment of juveniles in the Upper Paraná River floodplain and the consequent reduction in adult stock have impacts on the fisheries in the region, including in the Itaipu Reservoir, downstream from the plain (Gomes and Agostinho, 1997; Agostinho et al., 2004b).

After the formation of Porto Primavera Reservoir in 1998, there was a decrease in the duration of all discharge above the 350 cm level. As a result, water spillage over the main river channel diminished, and the different degrees of connection between fluvial channels and lentic water bodies also decreased (Souza Filho, 2009). This has implications for the availability of habitat for the initial growth of migratory fish. Then, when larvae or juveniles of these fish reach the Paraná River and do not find the flooded plain or other temporary flooded habitats, they may not survive. In the first case, they could serve as prey due to the absence of shelter and the diminished turbidity of the water (retention of suspended material in the reservoirs upstream) in the river. In the second case, they find flooded areas, but with early retraction of the water, they will die by desiccation and/or predation in the return to the river due to their small size (Agostinho et al., 2004b).

Important conservation initiatives have already been taken to protect the remaining floodplain stretch of the

Upper Paraná River. They are the "Área de Proteção Ambiental das Ilhas e Várzeas do rio Paraná" (a protected area), "Parque Nacional da Ilha Grande" (a National Park), and the "Parque Estadual das Várzeas do Rio Ivinheima" (a State Park), this last as a compensation measure for the inundation of a stretch of the floodplain by the Porto Primavera Reservoir. However, for protection to be effective, it is necessary to make changes in the rules of operation of the dams located upstream of the plain. According to Meurer (2004), who analyzed hydrometrics data between 1985 and 2002, the levels of 600 cm and 700 cm measured in the hydrometric station of Porto São José have recurrence intervals of 2.64 years and 5.75 years, respectively. This author also indicates that the 474 cm level represents the limit of the floods that have annual recurrence intervals. Thus, manipulation of the discharge of the dams upstream would ensure the occurrence of potamophases with the potential to assure recruitment success of long distance migratory species at an interval of two or three years. Another important consideration would be monitoring of the hydrometric levels and occurrence of fish larvae in the Ivinheima River. This should indicate the proper moment to initiate the potamophase in the Paraná River, which, preliminarily, according to the findings of this paper, appears to be in January. In relation to the intensity and duration of the potamophase, in general, recruitment responded better when potamophase intensities reached above 610 cm and water levels above 450 cm lasted over a period of 50 consecutive days. The former happened in 2006-2007 and was related to the highest abundance of YOY observed in this study, and it could serve as a reference. In this period, the level of the Paraná River reached 645 cm; levels above 610 cm lasted 38 consecutive days, above 540 cm lasted 50 days and above 450 lasted 57 days.

Exceptional flood events, as described above, are related to extreme (strong) events of the El Niño Southern Oscillation (ENSO), as in the case of 1991-1992, which resulted in exceptional floods with positive influences on recruitment. In addition, moderate ENSOs only produce relevant floods in the area if they happen after other extreme events (such as in 1992-1993) or after moderate events (2005-2006 and 2006-2007). Fernandes et al. (2009) showed that the strong ENSO of the flood period of 1997-1998 had positive effects on the captures neutralized by the retention of water during the filling of Porto Primavera Reservoir, followed by two events of drought (La Niña). The absence of relevant floods and the response to the intensity of recruitment of YOY during the El Niño of 2002-03 demonstrated the regulation capability of the reservoirs upstream.

Other impacts related to dams upstream of the plain are the retention of nutrients, oligotrophication of the plain (Agostinho et al., 2007b) and the high daily variations in water level (Souza Filho et al., 2004a). Despite these impacts, the artificial control of the floods through discharge manipulations of the dams, especially Porto Primavera (located immediately upstream of the floodplain), could become an important tool for the conservation of long-distance migratory species in the floodplain. Nonetheless, in Brazil, the use of this control is still not incorporated into the operation routines of dams. However, there are some studies (Godinho et al., 2003; Agostinho et al., 2004a; Pelicice et al., 2005; Pompeu and Godinho, 2006) pointing to this possibility as an important management action to improve recruitment of migratory species, especially when floodplains are located downstream from dams.

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