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SPATIAL AND TEMPORAL DISTRIBUTION OF SARDELA, *Hypophthalmus edentatus* (PISCES, SILUROIDEI), IN THE AREA OF INFLUENCE OF THE ITAIPU RESERVOIR (PARANÁ, BRAZIL)

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ABSTRACT. The sardela (*Hypophthalmus edentatus*), restricted to the downstream segment of Sete Quedas Falls before the Itaipu reservoir closure, dispersed in the upper segments of the river Paraná basin after the end of this natural barrier. Its distribution and abundance in the basin between the mouth of the rivers Iguaçu and Paranapanema, and its daily vertical migration in the Itaipu reservoir are analysed. The sardela is the main species of commercial fishery. Experimental fisheries were carried out using gillnets with different mesh size in 14 sampling stations from November 1983 to October 1989. Data are expressed in catch (number and weight) per unit effort (1,000 m^2). The sardela adults occupy more lentic environments in this portion, especially in the internal areas of the Itaipu reservoir. Juveniles are restricted to the reservoir, marginal lakes of the floodplain or in adjacent sites close to these environments. Seasonal changes are influential in the catches. Sardela density is higher in depths up to 5 meters from the surface, showing changes in density in the different layers of the water column and migrating to the surface and shallow areas at dusk and to deeper and open areas at dawn. These vertical distribution patterns are discussed according to zooplankton concentration, its main food, and according to its more important predator in this environment, the curvina

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(*Plagioscion squamosissimus*). It is suggested to professional fishery that it is feasible to install gillnets in open areas and at the subsurface, with the purpose of increasing fishery efficiency on the sardela and to reduce immature mortality of other species equally important to the regional fishery.

Key words: reservoir, river Paraná, vertical migration, Hypophthalmidae.

DISTRIBUIÇÃO ESPACIAL E TEMPORAL DA SARDELA *Hypophthalmus edentatus* (PISCES, SILUROIDEI), NA ÁREA DE INFLUÊNCIA DO RESERVATÓRIO DE ITAIPU (PARANÁ, BRASIL)

RESUMO. A sardela, restrita aos segmentos abaixo das antigas Sete Quedas antes da formação do reservatório de Itaipu, dispersou-se pelos segmentos superiores da bacia do rio Paraná após o alagamento desta barreira natural. Neste trabalho, analisou-se sua distribuição atual e abundância, no trecho da bacia compreendido entre a foz dos rios Iguaçu e Paranapanema, além de seus deslocamentos verticais diários no reservatório de Itaipu, onde é a principal espécie nos desembarques da pesca profissional. Pescarias experimentais foram conduzidas com redes de espera, de diferentes tamanhos de malha, em 14 pontos de amostragem, durante o período de novembro de 1983 a outubro de 1989, sendo os dados expressos em captura (número e peso) por unidade de esforço. A sardela ocupou os ambientes mais lênticos do trecho estudado, particularmente abundante nas áreas mais internas do reservatório de Itaipu, sendo suas formas juvenis confinadas a esta represa, às lagoas marginais da planície de inundação, ou a pontos contíguos a estes ambientes. Variações sazonais foram marcantes nas capturas da espécie. A densidade da sardela foi maior em profundidades até 5 metros da superfície, mostrando, no entanto, variações de densidade nos diferentes estratos da coluna de água: migrando para a superfície e áreas rasas ao anoitecer e para o fundo em águas abertas ao amanhecer. Tais padrões de distribuição vertical são discutidos em relação às concentrações do zooplâncton, seu principal alimento, e à de seu predador mais importante neste ambiente, a curvina *Plagioscion squamosissimus*. Sugere-se à pesca profissional a instalação de redes de espera em águas abertas e sub-superficiais como medida para aumentar a eficiência na captura da sardela, reduzindo também a mortalidade de imaturos de outras espécies importantes na pesca regional.

Palavras-Chave: reservatório, rio Paraná, migração vertical, hypophthalmidae.

INTRODUCTION

The sardela (*Hypophthalmus edentatus*) which was absent in the fisheries before the damming of the river Paraná (Itaipu Binacional, 1979), soon became one of the most important fish resources in the first years of the Itaipu Reservoir. As it is the only planktophagous-filterer species in the region, the sardela has a diet basically composed of zooplanktonic elements (Carvalho, 1980, Lansac Tôha *et al.,* 1991). Its remarkable reproductive capacity (Benedito, 1989) made it cope successfully with the high density of planktons in the years following damming. With the disappearance of the Sete Quedas Falls which had limited it to stretches in downstream basin, the sardela spread to the high river Paraná and occupied the floodplain upstream and other dammings which occurred afterwards.

In spite of the abundance of the species in the initial period of colonization of the reservoir, its participation in hauls became important only in the last years (SUREHMA-Itaipu Binacional, 1987; FUEM-Itaipu Binacional, 1990) when catching techniques were learned by the local fishermen. The commercial exploitation of sardela in the Itaipu reservoir made by gillnets amounted to 405 tons/year during the period 1987-1993 and contributed to about 27% of total fishing. It is thus the principal species caught locally (Agostinho *et al.,* in press - a). However, the mortality of young specimens of other species (which are also relevant in professional fishing) has been getting higher since the nets especially used for sardela catches bring up also immature specimens of the great majority of other species hauled in the reservoir (Gomes and Agostinho, in press; Agostinho *et al.,* in press - b).

The present research aims at investigating the distribution and abundance of sardela in the Itaipu reservoir and in the areas recently occupied by the species. Its vertical distribution standard in the regions of higher density will be studied too.

MATERIALS AND METHODS

For the present study catches were undertaken in 14 areas in the stretch of the river Paraná between the rivers Iguaçu and rivers Paranapanema, including the Itaipu reservoir. 10.241 specimens were caught. Sampling places and periods in these areas are shown in Figure 1.

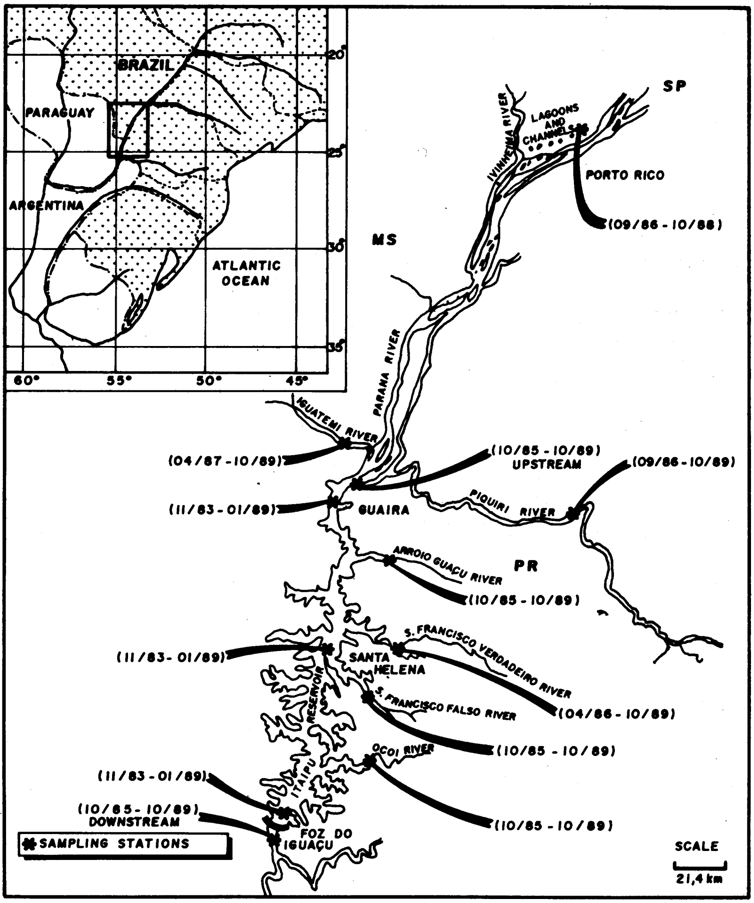

Figure 1: Place of sampling stations (periods of collection are between parentheses).

Spatial distribution, abundance and length composition were analysed from samples obtained by gillnets with 3, 4, 6, 8, 10, 12, 14 and 16 cm meshes, measured between opposite knots, exposed during 24 hours with at least two daily reviews. Besides, the effort used (m^2 of net) in each sampling, total weight (g) and length (cm) for each caught specimen were recorded.

To analyse the vertical and horizontal distribution of the species in areas of great abundance of sardela (Santa Helena and Foz) the catches in two distinct places were taken into consideration: one was localized in deep open areas (Point A) and the other in protected shallow areas, close to the bank (Point B). In the case of the latter, a complex of 50 m nets in Point B and a complex of 20 m nets in Point A were used. These were placed in different depths (A_1 = surface; A_2 = 5 m; A_3 = 10 m; A_4 = 15 m; A_5 = 20 m). Catches per unit of effort (CPUE) were determined by the formula:

$$\text{CPUE} = \frac{C}{E} * 1,000$$

where:

CPUE = number of individuals (or weight) per 1,000 m^2 of net/24 hours;

C = number of specimens (or weight) caught;

E = effort used (in 1,000 m^2 of net).

Previous to analysis, catches were transformed in log (CPUE + 1) as suggested by Green (1979) and the logarithmic data were plotted seasonally for each collecting station. The influence of variables, effort, place, year and season, with regard to the catch of sardela was estimated through ANOVA. Differences in species frequency among the samples of Points A and B and in different depths were estimated by χ^2 test (Siegel, 1975).

Constancy of species in sampling was estimated for each sampling station by the following formula proposed by Dajoz (1973):

$$C = P * 100 / Q$$

where:

C = constancy of occurrence,

P = number of collections in which species occurred,

Q = number of collections undertaken.

The species was considered constant in a determined environment when C was greater than 50%; accessory when C was between 25% and 50% and accidental when below 25%. Time variations in relative abundancy and length composition were analysed for areas where catches exceeded 50 specimens.

RESULTS AND DISCUSSIONS

Experimental fishing undertaken in a stretch of the river Paraná basin between the rivers Paranapanema and Iguaçu shows that the sardela has an ample distribution in the region. It is absent only in the river Piquiri. The analysis of catches per unit of effort in fishing (CPUE) and its constancy in sampling (Table 1) reveal, however, that its relative biomass and presence are relevant only in the innermost areas of the Itaipu

Reservoir (Santa Helena = 5.6 kg/1,000 m^2 of net/ 24 hours, with a record in all samples; Foz = 12.5 kg/1,000 m^2 of net/24 hours and occurrence in 96% of samples). Values obtained in catches of the species in these environments were equivalent to those related to the total biomass in experimental fishing undertaken in various tropical river systems (Welcomme, 1979). Among the various sampling places, values of CPUE in kg/1,000 m2 of net/24 hours were of slight relevance in Guaíra, the starting point of the reservoir (0.9), in two of its left margin tributaries (Ocoí - 1.8 and São Francisco Verdadeiro: 1.4) and in lentic environments (0.9).

Table 1: Values of catch per unit of effort (CPUE) and constancy in samples of sardela in different sampling stations.

Stations	N	Weight (Kg)	Effort	CPUEn	CPUEp	A	O	C
Reservoir	**9932**	**1980.36**	**352159.8**	**31.82**	**6.34**	**141**	**126**	**89.4**
Guaíra	486	91.12	103645	4.69	0.88	47	34	72.3
Santa Helena	2670	575.47	103667.8	25.76	5.55	47	47	100.0
Foz do Iguaçu	6776	1313.76	104847.0	64.63	12.53	47	45	95.7
Tributaries*	**297**	**60.43**	**73351.5**	**4.05**	**0.82**	**110**	**27**	**24.5**
Ocoí	178	34.65	19044.0	9.35	1.82	28	12	42.9
São Francisco Falso	11	2.13	19285.6	0.57	0.11	29	2	6.9
São Francisco Verdadeiro	105	22.95	16562.2	6.34	1.39	24	10	41.7
Arroio Guaçu	3	0.70	18459.7	0.16	0.01	28	2	7.1
river Paraná	**10**	**2.93**	**33501.7**	**0.30**	**0.09**	**58**	**7**	**12.1**
Upstream Reservoir	1	0.44	18297.5	0.05	0.02	29	1	3.4
Downstream Reservoir	9	2.49	15204.2	0.59	0.16	29	6	20.7
Tributaries(river Paraná)	**5**	**1.27**	**53499.7**	**0.09**	**0.02**	**61**	**4**	**6.6**
Piquiri	-	-	26775.7	-	-	22	-	-
Iguatemi	2	0.41	18610.0	0.11	0.02	15	1	6.7
Ivinheima	3	0.86	8114.0	0.37	0.11	24	3	12.5
Floodplain	**196**	**47.14**	**62136.5**	**3.15**	**0.76**	**168**	**38**	**22.6**
Lakes	143	34.26	37867.1	3.77	0.90	96	20	20.8
Channels	53	12.87	24269.4	2.18	0.34	72	18	25.0

CPUEn = catch per unit of effort in numbers (number of individuals/1,000m^2 of net); CPUEp =catch per unit of effort in weight (kg/1,000m^2 of net); A = number of samples at station; O = number of presence of species; C = constancy (%); * = left bank tributaries of reservoir.

As shown in Table 2 its catch was influenced to significant levels by the season of the year ($p < 0.01$), year ($p < 0.02$) and by interactions between effort and season ($p = 0.03$) and effort-site ($p < 0.02$).

Table 2: Summary of results of analysis of variance.

Sources of variation	G. L.	F	P
MAIN EFFECTS			
Year	1	6.096	0.016
Effort	1	0.001	0.976
Season of the year	3	9.151	0.000
Site	6	1.028	0.413
INTERACTIONS			
Effort x Season of the year	3	3.193	0.028
Effort x Site	6	2.660	0.020

Low catches and sporadic records of sardela in lentic environments show that the species has a preference for sluggish or stagnant waters as already discussed by Carvalho (1980) and Oliveira (1981). This fact has been corroborated by tendencies in the process of colonization of the basin segment upstream of Guaíra by the damming of Itaipu after the disappearance of the Sete Quedas Falls, a geographic barrier that limited its distribution. In this process, the species occupied lentic and semi-lentic areas of the floodplain with sporadic presence in plateau rivers such as Iguatemi and Ivinheima the rivers and absence in the river Piquiri which has the greatest declivity among all the other tributaries of the river Paraná in the studied stretch.

Transformed values of catches per unit of effort (log (CPUE + 1)), calculated for annual and seasonal periods in places and group of places where catches were more relevant, are shown in Figure 2. It may be verified that in the reservoir these values were higher in the first year of sampling (1983-1984) while decreasing in the following year. In the following three years values remained approximately constant but presented another decrease in the 1988-1989 period. These tendencies reflect the opportunism of the species in the process of colonization using the abundance of zooplankton which, though not evaluated in the present case, is generally confirmed in the first years of the reservoir formation (Petts, 1984). Follow-up of fishing hauls in the Itaipu Reservoir, begun in 1987 and analysed by Agostinho *et al.* (in press - a), reveals slightly distinct tendencies in annual abundance for the period corresponding to that of the present study. Thus, haul of species decreased in 1987 and increased in the following two years. This discrepancy may be explained by the recent character of this source in the region. From 1987 the increase in its catch for commercial fishing is the result of a greater experience of fishermen in its exploitation. Thus, the discrepancy may be much more related to an increase in fishing efficiency than to abundance of supply.

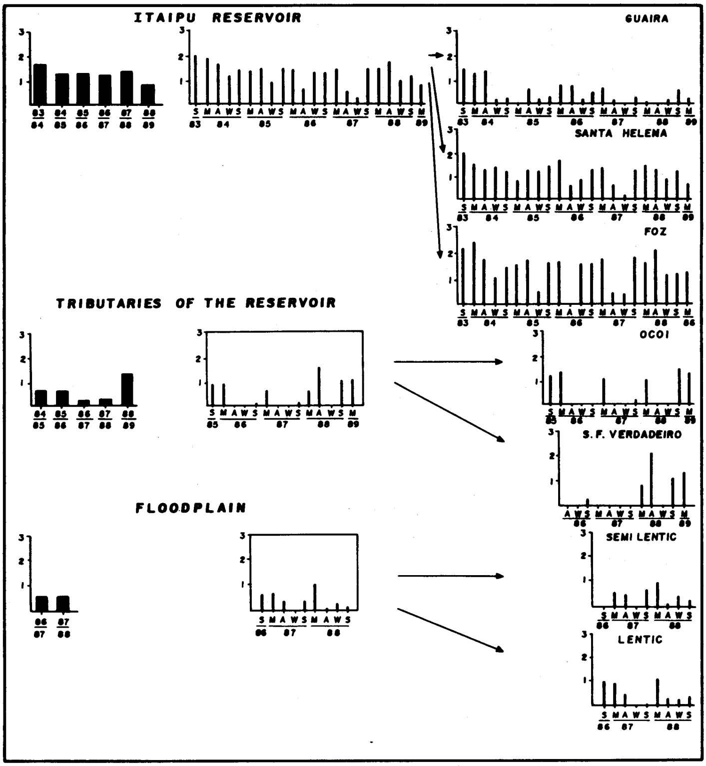

Figure 2: Temporal variations in catches of the *H. edentatus* in different environments in the river Paraná basin (stations with CPUE < 2 are excluded; CPUE = number of individuals/1,000m^2 of net; S = spring; M = summer; A = autumn; W = winter).

Surveys undertaken in the region before the formation of the Itaipu reservoir comprising three years of sampling, resulted in only three specimens of sardela (Itaipu Binacional, 1981). This fact is explained by the scarcity of lacustrine environments in the neighbouring areas because the river Paraná, downstream from Sete Quedas, flowed into a tectonic chasm with up to 100m cliffs. A year after the formation of the reservoir, when collections were being observed for this study, catches were high (685 specimens in November 1983) with a high percentage of big-sized specimens. In 1983/84 the species was a principal factor in experimental fishing contributing with 18.6% of the total biomass caught (FUEM-SUREHMA/Itaipu Binacional, 1985).

The apparent contradiction between the low incidence of the species in the region before the dam construction and abundant catches of adult individuals after a year of closure leads to three suppositions as to the origin of these initial supplies, especially of the adult portion. In the first place, they would have been recruited as adults in restricted lake areas in the basin. In this case, they were not identified nor sampled before the closure. Second, they would have originated from ascendant migrations (from exceptionally big schools) in the period immediately previous to closure, coming from flooded areas of the lower segments. Thirdly, they would have originated from the reservoir proper as a result of an extremely successful reproduction immediately after enclosure, with a very high growth rate accompanied by a precocious maturation during the first year. Restrictions due to the topographic region make the first supposition highly improbable. The ascendant migration of *Hypophthalmus marginatus* has been recorded in the Tocantins basin by Carvalho and Merona (1986) who describe it as a typical phenomenon of young individuals. In spite of low catches, the seasonal register of the species in the tributaries of the Itaipu reservoir (Figure 2) may suggest that migration may occur but not in such a massive manner. The recording of reproductive activity during almost all the months of the first two years of sampling, with two peaks of spawning in the first (Benedito, 1989), indicates the reproductive flexibility of the species, giving it the characteristics of an opportunistic species. The formation of a vast pelagic zone and high food availability, compounded to the fact that it is the only planktophagous-filterer species of the region, gave the species opportunities for the full achievement of its biological potencials. The lack of information on the size composition of initial supplies in the first year after the closure and the difficulty of determining the age of the species through conventional methods of length and age ring frequency did not permit the elucidation of these aspects.

The seasonal oscillations of catches shown in Figure 2 were verified in all the sampled environments although they were more salient in the reservoir tributaries. Decrease in locomotor activity and/or the concentration in deeper areas during the winter may explain the least values for CPUE during this period in the reservoir. The evasion of supplies through migration towards external areas outside the reservoir seems to be improbable since the species is capable of developing all its cycle in the enclosed area. Further, individuals in all phases of gonodal maturity (Benedito, 1989), their eggs and larvae (Nakatani *et al.*, 1991) and juvenile forms have been found in it (Figure 3). Agostinho *et al.* (1992) emphasize that this species is the only one (among nine others which are of the greatest importance in commercial fishing) that has its complete cycle in the Itaipu reservoir. Thus the strong seasonal factors verified in the CPUE values in the reservoir tributaries may be explained through the process of dispersion ruled by intrinsic phenomena of supply dynamics. The same process must have occurred during the occupation of other environments at upstream Guaíra, available through the disappearance of the Sete Quedas. However, in this case, the establishment of the species occurred as shown by the existence of young and adult forms in the lakes of the floodplain. Figure 3 also shows salient differences in the composition of length in samples obtained from the rivers São Francisco Verdadeiro and Ocoí, tributaries of the Itaipu reservoir, with a remarkable presence of young forms in the latter. Distances between the sampling places in these rivers and other stretches dammed by the Itaipu reservoir, but not for the river Ocoí, explain this fact. Confinement of young specimens to lentic areas, salient in this study, was not verified in those of other species (*H. marginatus*) commented on by Carvalho and Merona (1986) who register them as migrating in lotic areas of the river Tocantins, below the dam of Tucuruí.

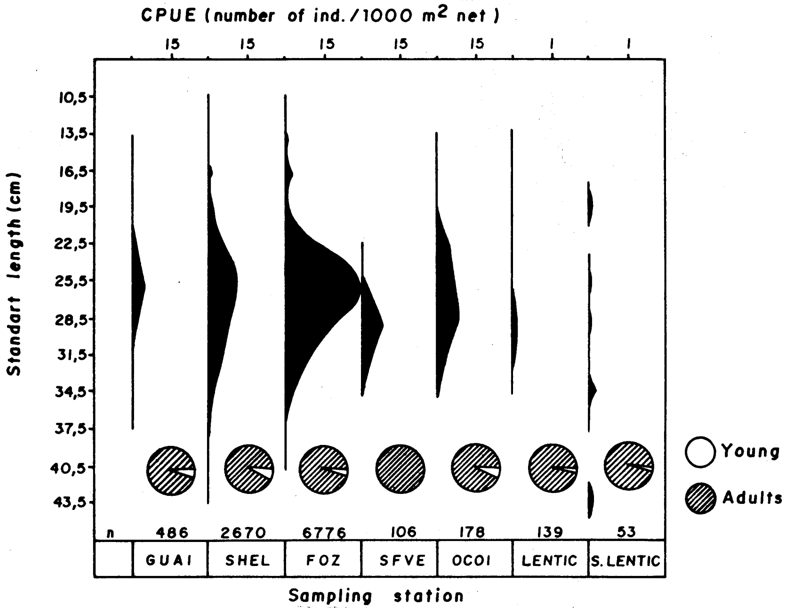

Figure 3: Distribution of relative frequency according to standard length class of *H. edentatus*, according to sampling stations.

Variations in catches per unit of effort between deep/open areas (A) and shallow/marginal ones (B) in different periods of the day are presented in Figure 4. It reveals that, during the day, the species concentrated itself in open and deeper areas. It moved to shallow and marginal ones in the evening, returning back in the morning, with considerable differences in CPUE (χ^2; p = 0.05). Vertical distribution of the species in different periods of the day, also shown in Figure 4, reveal greater concentration of the species in depths close to 5 meters from the surface independent of the periods under examination. Relative density, however, varied in different depths according to the period of the day. Density in deep layers showed itself higher during the day, with movements towards the surface in the evening and with a return to the depth in the morning. Daily vertical migrations are common among pelagic species especially in sea and river planktophagous. (Levy, 1990) This standard of vertical migration in zooplanktophagous has been assumed as a mere alternation between the feeding and the shelter habitat (Wooton, 1991). On the other hand, Bret (1971) numbers the functions of these movements, as (1) trophic movements caused by prey persecution; (2) flight from predators: the search for deeper areas to reduce predation; (3) homeostatic control: the search for colder waters after the feeding period where waste of energy is less. Clark and Levy (1988) suggest that a single explanation for the phenomenon is inadequate. They emphasize that it seems to be dependent on the size of the individuals, on the species and on other environmental factors. (Hamrin, 1986). In the present study where it was confirmed that a great number of individuals concentrated themselves permanently at 5 m below the surface and thermocline, when present, is situated below 30 m (SUREHMA-Itaipu Binacional, 1989), the thermic control hardly seems to explain this phenomenon. On the other hand, water transparency in the area under study varying between a minimum of 0.40 m and a maximum of 2.30 m, with an annual average of 1.16 m (Agostinho *et al.*, 1992) may give some protection to the species against predation in the more superficial layers and grant a lesser interval in diel migration to the zooplankton. It should be emphasized that the principal predator of this species, the curvina *Plagioscion squamosissimus*, has a peak in feeding activity in the early morning and in the middle of the day (Hahn, 1991) and that data of vertical distribution of this predator in different hours of the day (although not conclusive, and this is why they are not related in this paper) show an inclination to accompany the vertical distribution of its principal prey.

Data of the vertical distribution of zooplankton obtained by SUREHMA-Itaipu Binacional (1989) and Tomm *et al.* (1992) indicate that it presents greater concentration around depths of 5 m. These facts seem to indicate that the mechanics regulating the daily vertical movements of sardela are the result of interactions between the species, its predators and prey, influenced in space by water transparency conditions.

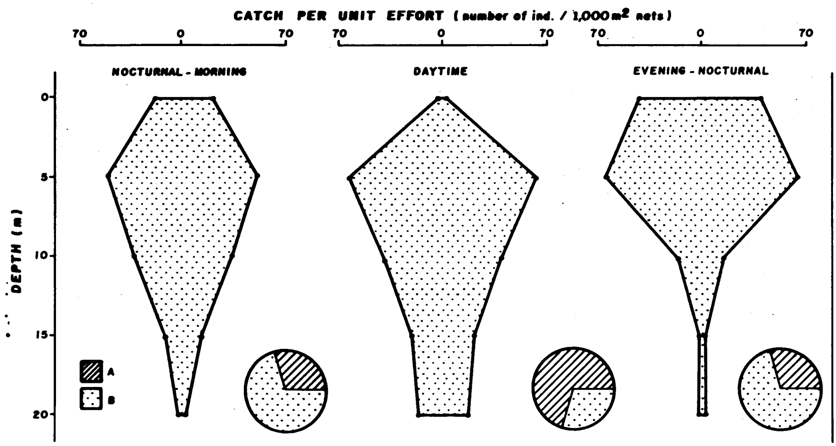

Figure 4: Catches of *H. edentatus* with regard to time of day in points A and B and in different depths in point A.

CONCLUSIONS

Some conclusions may be taken: (1) sardela (*H. edentatus*) occupies essentially the more lentic environments of the stretch of the river Paraná basin between the rivers Paranapanema and Iguaçu, being extremely abundant in the innermost areas of the Itaipu reservoir; (2) it presents salient seasonal oscillations in abundancy, with lower CPUE values during the winter; (3) it has its immature forms restricted to the reservoir area, to the marginal lagoons or in contiguous points to these environments; (4) in the reservoir it concentrates in depths close to 5 m below the surface showing a discrete migration towards the surface and shallow marginal areas during the evening, and towards the bottom in open areas during the day; (5) in commercial fisheries its exploration will have a lesser impact on immature forms of other equally important species if the nets are set in open and subsurface waters.

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