Abiotic Factors Influencing Piranha Attacks on Netted Fish in the Upper Paraná River, Brazil

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Abstract.—The influence of selected abiotic variables on the frequency of attack by piranhas *Serrasalmus spilopleura* and *S. marginatus* on gill-netted fish was evaluated to identify fishing strategies suitable for environments with high piranha densities. The percentages of attacked fish were recorded during monthly gill netting in the main channel and two lagoons, during both dry and wet periods, in the lower Ivinheima River (22°40′–22°50′S; 53°10′–53°40′W), Paraná River basin, Brazil. In the channel, the catch was removed three times per day, and in the lagoons it was removed every 3 h. Attack frequency on netted fish was correlated positively with temperature, and was more intense at temperatures higher than 25°C. Most piranha attacks were diurnal, and attacks were most intense between 1200 and 1500 hours. To minimize attacks on netted fish, we recommend that gill-netting strategies focus on avoiding areas and periods with high water transparency and temperatures.

Most teleosts ingest their prey whole. Therefore, prey size is often a strong limitation on predation. However, certain South American serrasalmids are able to tear away fragments from their prey and may attack animals considerably larger than their gape width. Piranhas, like other animals with the same ability, such as sharks (Squalidae) and barracudas *Sphyraena* spp. can be harmful to commercial fisheries because they attack fish caught in fishing gear (e.g., gill nets and trotlines) and eliminate or reduce their commercial value. Another relevant issue is the stealing of baits soon after deployment of the fishing gear and the destruction of gear (Agostinho et al. 1994). Fishery losses caused by piranhas have led fishers to develop specific avoidance strategies. For example, fishers in the Amazon basin remove fish from gill nets frequently during a 24-h period, and use larger meshes that permit the free transit of the piranhas through the nets (Goulding 1979; Smith 1979).

Two species of piranhas, *Serrasalmus spilopleura* and *S. marginatus,* occur in the flooded plain of the upstream Paraná River. In this region, commercial fishing is undertaken primarily by using trotlines and gill nets of various mesh sizes. Strategies for diminishing losses to piranha attacks include: (1) preferential use of nets with cotton multifilaments that are more resistant to the piranha attacks; (2) removal of the catch several times per day; (3) frequent alternation of fishing localities thus avoiding attraction of piranhas to frequently fished locations; (4) preferential use of areas away from aquatic macrophyte banks, and (5) operation of trotlines at night only, and avoidance of nights with bright moons.

These fishing strategies are based on the empirical knowledge of fishers, obtained from trial and error, and the use of intuitive sense, but without a scientific base. In this study, we examined the influence of selected abiotic variables on the

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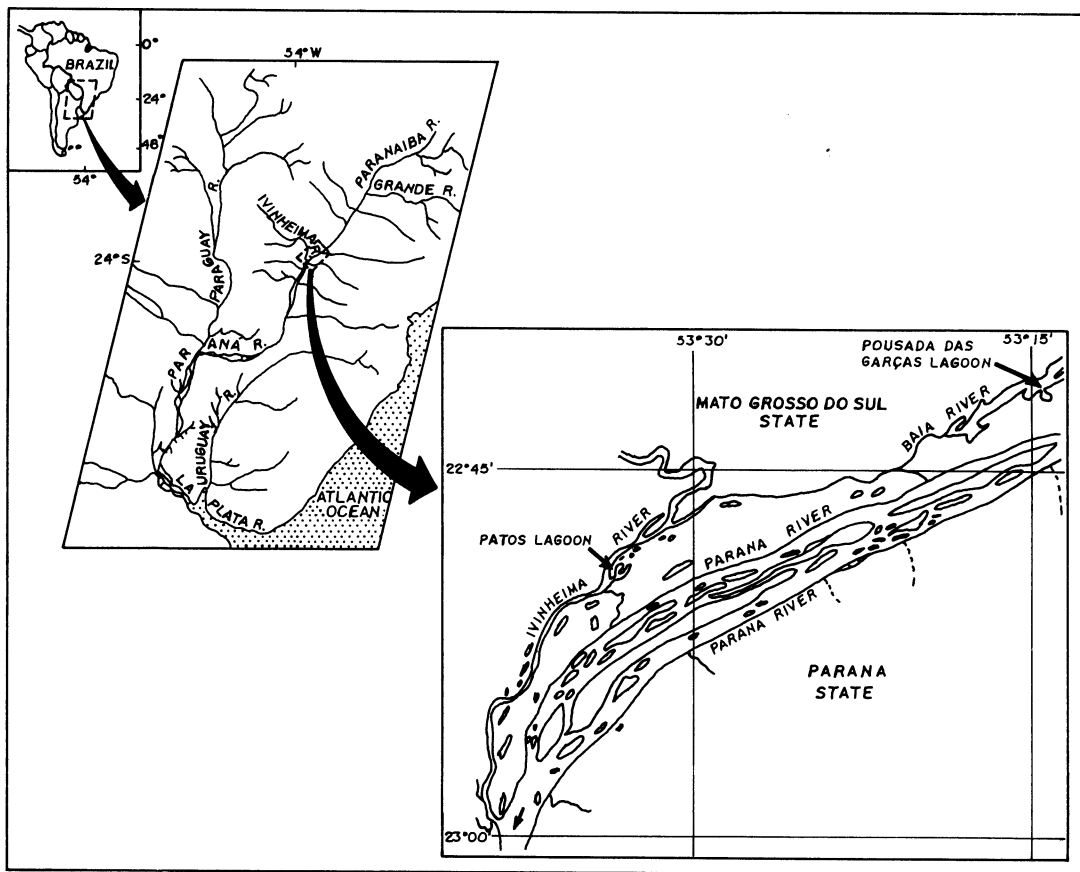
FIGURE 1.—Sampling stations in the Ivinheima River, Paraná River Basin, Brazil.

frequency of piranha attacks on netted fish, with the objective of identifying strategies suitable for fishing with gill nets in environments with high piranha densities. Although our work focuses on piranhas, our findings may be useful against predators that cause similar problems elsewhere in the world (e.g., predation by turtles (Testudines) and gars *Lepisosteus* spp. in North America).

Methods

This analysis is based on experimental fishing undertaken during June 1987–May 1988 in a stretch of the lower Ivinheima River (22°40′–22°50′S; 53°10′–53°40′W), a tributary of the west margin of the upper Paraná River (Figure 1). Nylon gill nets were 1.7 m tall × 20.0 m long, with meshes of 3, 4, 5, 6, 8, 10, 12, 14, and 16 cm (stretched measure). Nets were fished at the surface for 24-h periods, once per month: the catch was removed at 0730, 1830, and 2200 hours.

During August 1987 (dry season) and February–May 1988 (rainy season), gill nets were fished at the Pousada das Garças and Patos lagoons connected to the Baia and Ivinheima rivers, respectively (Figure 1), with the equipment and installation procedures described above; at these locations, fish were removed every 3 h.

All netted fish were identified to species and measured for total length to the nearest 1 mm. The marks left by the piranha attacks on the fish's fins, body, or both were noted and recorded. Attacks by other predators (e.g., otters, turtles) occurred infrequently and also were recorded. Piranhas produced precise incisions, whereas other predators destroyed the tissues quite extensively.

Water temperatures were obtained with a thermistor, and transparency was determined with a 30-cm-diameter Secchi disk. Water levels, taken for the Ivinheima River at Porto Sumeca (Mato Grosso do Sul State), were supplied by the Binational Itaipu Power Company. The values used represent the monthly means of information re-
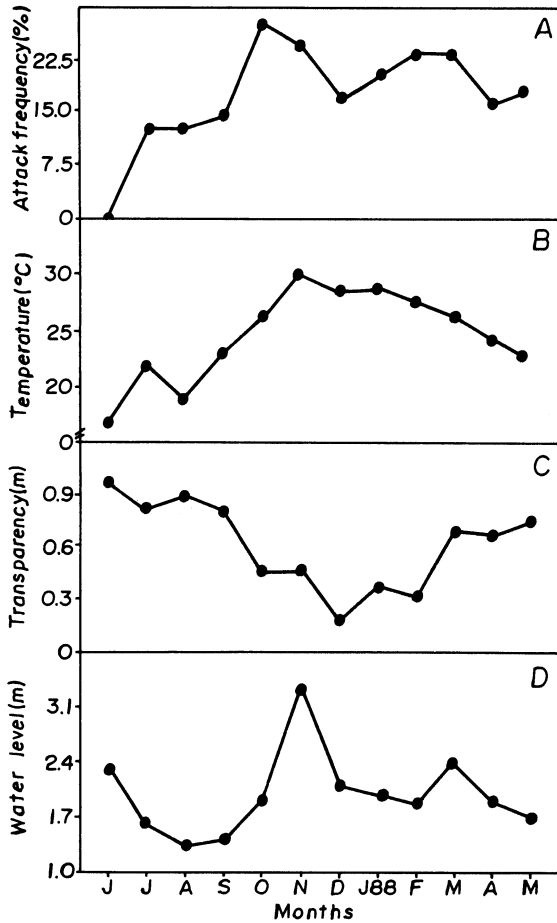
FIGURE 2.—Monthly variation in (A) percentage of gill-netted fish attacked by piranhas, (B) water temperature, (C) water transparency and (D) water level at the Ivinheima River from June 1987–May 1988. Water level values are relative to a fluviometric rule positioned 224 m above mean sea level.

corded daily during the collection period. We used multiple regression to examine the relationship between the percent of fish attacked (arcsine transformed) in each net and temperature, water transparency, and water level.

Results

Water temperature increased from 16.8°C in June to 30.1°C in November, and decreased to 21.5°C in May (Figure 2B). Transparency (Figure 2C) followed a similar, but inverse, pattern, with a low transparency of 0.15 m in December, and a high transparency of 1.0 m in June. Water level (Figure 2D) fluctuated from a low of 1.35 m in August to a high of 3.33 m in November. These water level values are relative to a fluviometric rule positioned 224 m above mean sea level.

Both piranha species were recorded in the catch.

Incidence of attacks on the netted fish varied monthly (Figure 2A). The incidence of fish attacked by piranhas was proportionally greater when water temperature exceeded 25°C, when water transparency was less than 0.60 m, and when water level was high. A reduction in the percent of attacked fish was observed in December, coinciding with water transparency of less than 0.20 m.

Attack frequency, water temperature, and transparency varied during 24 h periods when gill nets were fished in the lagoons (Figure 3). In all seasons, the frequency of attack on netted fish increased after 0600 hours, reached a maximum between 1200 and 1500 hours, fell gradually at dusk, and reached a minimum between 2400 and 0600 hours (Figure 3A). Incidence of attacks was lower in August when water temperatures were below 19°C, and higher in February and May when water
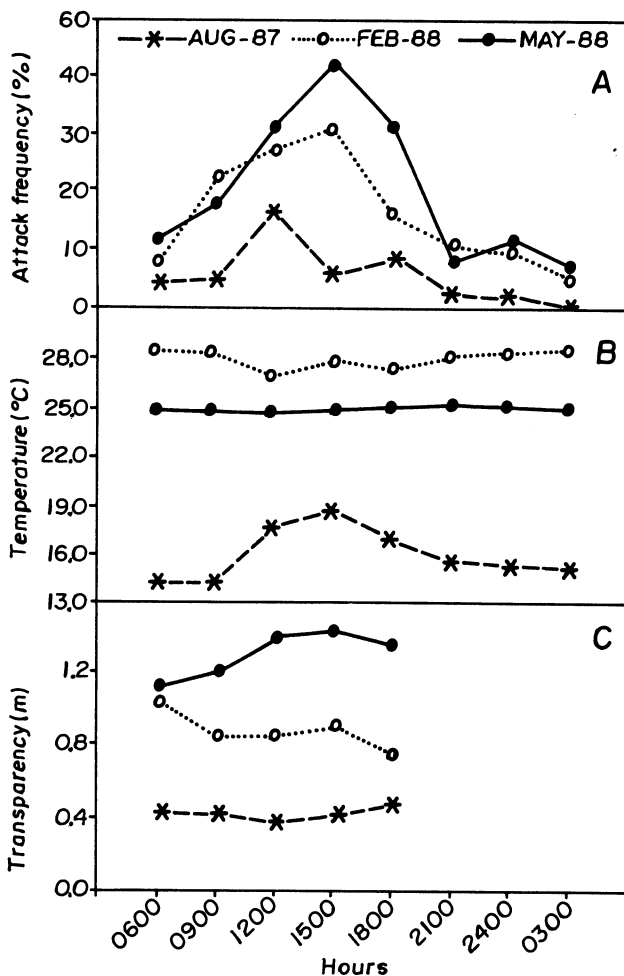
FIGURE 3.—Diel fluctuations in (A) percentage of piranha attacks, (B) water temperature and (C) water transparency in August, February, and May in the Pousada das Graças and Patos lagoons.

temperatures were above 24°C (Figure 3B). Transparency was greatest in May and lowest in August (Figure 3C). Diel variability in temperature was highest in August, whereas variability in transparency was highest during February and May (wet season).

Temperature and transparency were negatively correlated ($r = -0.886$, df = 10; $P < 0.001$). Also, temperature was positively correlated with water level ($r = 0.601$, df = 10; $P < 0.05$). There was no correlation between water level and transparency ($r = -0.298$, df = 10; $P > 0.05$).

Temperature and transparency both were correlated with attack frequency ($r = 0.780$, df = 10, $P < 0.003$, and $r = -0.640$, df = 10, $P < 0.025$; respectively). Independently, temperature accounted for 61% of the variability in attack frequency, and transparency for 41%. Attack frequency increased with temperature and decreased with increased transparency (Figure 4). There was no correlation between attack frequency and water level ($r = 0.106$, df = 10, $P > 0.05$).

Multiple regression analysis indicated a strong relation between attack frequency and the three independent variables (Table 1; model 1). The coefficient of determination (R^2) was 0.699, suggesting that 70% of the sum of squares of attacks were associated with the variation in temperature, transparency, and water level. The composite hypothesis that all three coefficients are 0 was rejected ($F = 8.298$; $P = 0.008$). Yet, only the partial regression coefficient for temperature was significantly different from zero (Table 1). Forward stepwise selection, backward elimination, and
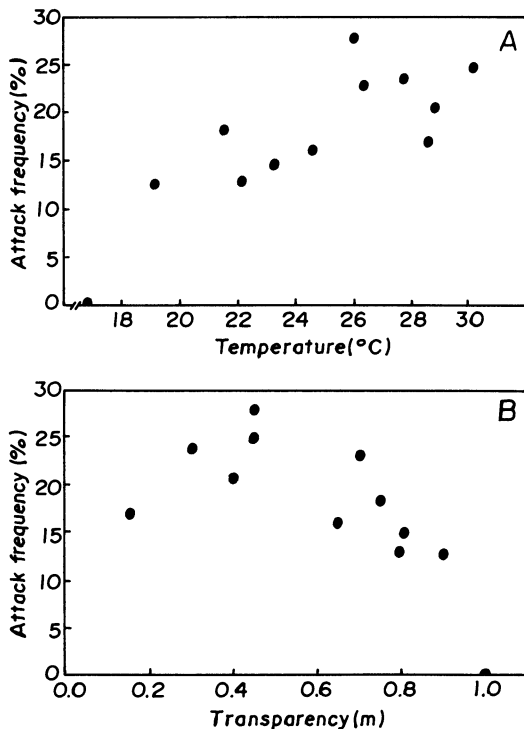
FIGURE 4.—Monthly values for piranha attacks in relation to (A) temperature and (B) water transparency recorded in the lower Ivinheima River, June 1987–May 1988.

Monte Carlo randomization resulted in the same outcome not shown. Multiple regression results were unsatisfactory due to a strong collinearity between transparency and water temperature. Therefore, we developed regression equations for transparency and temperature separately (Table 1: models 2 and 3).

Discussion

High frequency of piranha attacks was correlated with high temperatures and low transparencies that occurred during periods of heavier precipitation and input of particulate matter into the aquatic environment. The effect of these two factors on predation must have, nonetheless, distinct mechanisms. Temperature probably affects predation through its effect on predator metabolism, whereas transparency affects the visual detection of the prey.

High temperatures increase the rates of gastric evacuation and systemic demand (Wootton 1990), augmenting feeding intensity and frequency. In our study, this augmentation was manifested as an increase in the frequency of attacked fish. Elliott

TABLE 1.—Relationship between frequency of attack (arcsine transformed) by piranhas (*Serrasalmus spilopleura* and *S. marginatus*) on gill-netted fish in the Paraná River, Brazil, and three independent variables in simple and multiple regression models.

Variable	Coefficient	SE	t	P
Model 1 ($N = 12$, $R^2 = 0.70$)				
Constant	−44.152	26.200	−1.685	0.130
Transparency (m)	16.283	12.646	1.288	0.234
Temperature (°C)	2.925	0.873	3.342	0.010
Water level (m)	−0.070	0.033	−2.119	0.067
Model 2 ($N = 12$, $r^2 = 0.41$)				
Constant	36.138	5.113	7.067	0.000
Transparency (m)	−20.364	7.736	−2.632	0.025
Model 3 ($N = 12$, $r^2 = 0.61$)				
Constant	−14.907	9.913	−1.504	0.164
Temperature (°C)	1.572	0.399	3.940	0.003

(1975) recorded increases in food consumption by brown trout *Salmo trutta* of various sizes acclimatized at different temperatures; however, he identified temperature thresholds after which the consumption rate decreased sharply. In our study, no decrease in the attack by piranhas was observed as a function of thermal increase, suggesting that there is no threshold below 30°C. Marques (1990) experimentally analyzed the rate of gastric evacuation of *S. spilopleura*; no gastric evacuation differences were found at temperatures between 25 and 30°C, although digestion rate decreased at 35°C. Braga (1976) verified experimentally that the optimum temperatures for the survival of related species of piranhas, *Pygocentrus* (=*Serrasalmus*) *nattereri* and *S. rhombeus,* were between 24.2 and 25.4°C.

The highest attack frequencies occurred during October to March, when the temperatures were above 25°C. However, frequencies during these months varied from 16 to 28% of the total number of netted fish. The variation may be attributed to interactions of temperature with transparency, pH, and photoperiod (Wootton 1990), or even endogenous rhythms such as those associated with reproduction.

Reduced transparency of the water column should restrict the detection of food by species that are visual feeders. Most Characiformes, which include the piranhas, are visual feeders, as opposed to the Siluriformes that rely mainly on chemical sense, or the Gymnotiformes that detect prey by electric fields (Britski 1978; Krammer 1990). Acoustic and chemical precision are advantageous for detecting prey at long distances, whereas visual

precision requires appropriate lighting and proximity to the prey (Keenleyside 1979).

The importance of vision for piranhas in feeding seems to be species specific, as shown by the divergent results obtained for different species. Ali and Raymond (1972), studying the histology of the retina of *S. marginatus,* concluded that this species does not depend primarily on vision for locating its prey. However, Sazima and Machado (1990) reported that *S. spilopleura* behaves like a visually oriented predator, employing cunning approximation tactics and dissimulation. Other studies have indicated that the piranhas have an exceptionally well-developed visual system (Ebbesson and Ito 1980; Schulte 1988; Nico 1990).

Assuming that visual orientation is important for piranhas, as well as for other piscivorous teleosts, choice and capture of the prey (Keenleyside 1979), and an increase in the attack frequency would be expected with improved visibility. This would be especially true in our study, where the visual skill of the prey was irrelevant because the prey were trapped in the net. The negative correlation between the attack frequency and water transparency, however, contradicted this hypothesis. Nonetheless, the data do show a reduction in attacks in December, when water transparency was exceptionally low. An increase in attacks was also observed during the hours and months where the visibility in the water was high. These results suggest that visibility is relevant, under thermal conditions close to the optimum for the species.

Interactions between the visual abilities of prey and predator may have resulted in evolutionary adaptation of the piranha to attack in conditions of intermediate visibility. Ali and Raymond (1972) showed that *S. marginatus* possess a retina adapted to evening vision. Conversely, Sazima and Machado (1990) reported that *S. spilopleura, S. marginatus,* and *S. nattereri* have a diurnal habit, and only a few larger individuals are active at night. Our results show that during 24-h periods, attack frequencies were highest in the hours with greatest incidence of light. Nico (1990) reported that juveniles of *Pygocentrus notatus,* had greater predatory activity during the morning hours, with a peak near 1100 hours, and little or no activity after sunset. Because aquatic visibility depends upon the interaction of various factors, it is expected that the different experiments would not present coincidental results for this factor. Moreover, we point out the controlling role of temperature and its interactions with other abiotic and biotic factors. Among the latter are the specific composition

and abundance of the local ichthyofauna and the use of alternative senses for prey detection. Olfaction, the lateral line system, and hearing are also well developed among the serrasalmids (Nico 1990; Ebbesson et al. 1981), and they can detect sounds and splashing of handicapped prey (Goulding 1980).

The seasonal changes in temperature and water transparency, with amplitudes of 13.3°C and 0.85 m, respectively, did not allow an accurate appraisal of the isolated influence of each of these factors on attack frequency. Considering the zoogeography of this family, we can expect water transparency to be more relevant in lower latitudes, where temperatures are high and relatively constant, but transparency is extremely variable throughout the year.

Implications to Fisheries

The propensity towards settling processes and retention of particulate matter by impounded rivers (Agostinho et al. 1994) contributes to the global increase of transparency in rivers. This is the case of the Paraná River in its Brazilian stretch, where there are 26 reservoirs larger than 100 km^2. Additionally, reservoirs generally act as thermal accumulators (Tundisi 1990). Increases in transparency and temperature in reservoirs and regulated rivers could increase piranha attacks, causing further problems for gill-net fisheries.

Strategies recommended to fishers to minimize piranha attacks on netted fish must take water transparency into account. Diurnal fishing with gill nets and trotlines is not advisable in the warm season in areas with high piranha densities. If fishing is to occur under these conditions, frequent removal of the catch from the nets is necessary to reduce susceptibility to attack. The use of gill nets with meshes larger than 10-cm stretch measure (Goulding 1979), although viable as a strategy for reducing the damage on equipment in the Paraná River and its main affluents, is not feasible for the reservoir environments, where more than 80% of the captures are made in nets with meshes smaller than 10 cm (FUEM-NUEPLIA 1990). Although fishing gill nets in different areas, or the removal of fish from gill nets during the critical periods of the day, may incrase the fuel and effort costs of fishing, it is probably an efficient measure for reducing losses from piranha attacks. Considering the importance of commercial fisheries in Brazilian reservoirs and the damage caused by serrasalmids (Braga 1976), we suggest that more detailed studies are needed to identify the depth, lo-

cation, and time factors affecting attacks so that gill nets can be fished most effectively. Such evaluations should consider the costs and benefits of modifying current fishing strategies.

Acknowledgments

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