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Rotenone calibration of fish density and biomass in a tropical stream sampled by two removal methods

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Abstract

A catch-depletion method was applied using two sampling gears in three sites of a small tributary of the Corumba River (Goiás State, Brazil) in two seasons. The gears were: a double stick net (DSN) in one site and electric fishing (EF) in two sites. The calibration of both gears was performed using rotenone. EF was almost sufficient to establish a complete local species list, but DSN was not. Underestimation of calculated density (N) and biomass (B) values for DSN and EF amounted to 62 and 29%, respectively. The results of N and B obtained by EF were too imprecise to calculate secondary fish production to be applied in a field bioenergetics model. We could not conclusively prove that mean body weight of sampled populations was significantly lower for fish caught by EF, although all of these means were higher for fish collected by rotenone, at each site and on two sampling occasions.

Introduction

In even small rivers, quantitative electric fishing sampling does not supply adequate density and biomass estimates and an underestimation problem still exists, even though this sampling method has fundamentally contributed to riverine fish studies since World War II (Reynolds, 1983). Nevertheless, Cormack's (1968) statement that no technique will provide accurate population density estimates remains valid, especially if the behaviour and biology of the target species are not understood (Larimore, 1961; Cormack, 1968). Consequently, different, 'combined sampling techniques' are recommended in rivers as well as a well-designed sampling program to understand and reduce sampling variability (Casselman et al., 1990).

Underestimation problems accompanying most sampling gears arise when sampling is conducted in mountain streams with high velocity (Cuinat, 1967) or tropical streams with low conductivity, fallen trees, overhanging shrub branches, dense bankside vegetation and seasonally strongly varying discharge (Payne, 1986; Lowe-McConnell, 1987). Such factors greatly restrain access of researchers to sampling sites and the subsequent sampling of stunned fish, when electric fishing is applied.

In the present paper, a tropical stream was sampled at one site in two seasons, with a double stick net employed for successive catches in addition to electric fishing, which was used as the main gear there. There still exists a conviction that the double stick net can be successfully used in fluvial ecosystems, for example in Venezuela and Brazil, and numerous attempts with different nets have been and are continuously undertaken for sampling fluvial ecosystems (Casselman et al., 1990; Pygott et al., 1990; Leslie & Timmins, 1992; Penczak et al., 1997b, 1998). For the calibration of both these applied gears rotenone was used afterwards. Of course we are conscious that this method is not without complications (Davies & Shelton, 1983), but among the already known ones only rotenone appli-

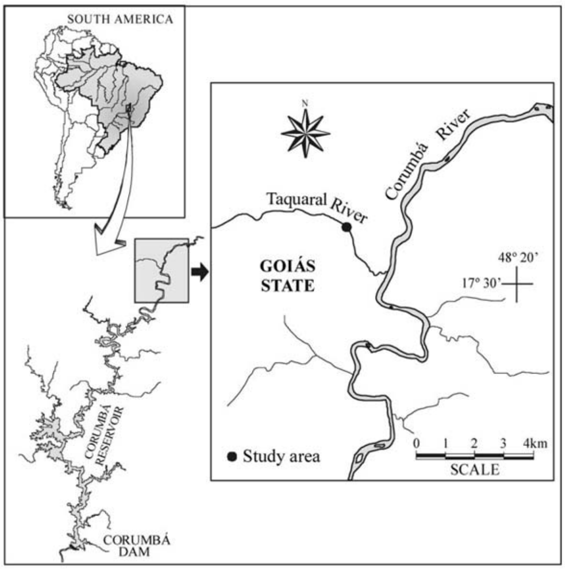

Figure 1. Map of Brazil showing location of the examined river, with an inserted map of the Taquaral River with marked place of sampling.

cation provides effectively collected fish samples, ones in which data on size, age structure and share of 0+ fish (recruitment) are most credible and close to the actual state.

The aims of this study were: (1) to estimate the species richness of fish and efficiency of a double stick net, and electric fishing, (2) to calibrate with rotenone the density and biomass obtained by both gears, and (3) to test a general hypothesis that capture efficiency is positively selective with respect to fish size (age), i.e. large specimens are easier to catch than small ones (Sulivan, 1956; Larimore 1961; Stewart, 1975; Reynolds & Simpson, 1978; Mahon, 1980; Reynolds, 1983).

Study area, material, sampling methods and data analysis

Study area

Three contiguous sites for fish sampling were located in the lower course of the Taquaral Stream, which empties into the Corumba River about 15 km upstream of the backwater of a newly created, large, man-made reservoir (Fig. 1). Vehicle access to a bridge located just upstream of site 3 (see below) was available on both sampling occasions (December 1996 and March 1997); from that place sampling equipment was carried to the sampling sites (Fig. 2). The sites differed significantly in canopy cover only. Shading in sites 1, 2 and 3 constituted 70, 80 and 1–2%, respectively. In site

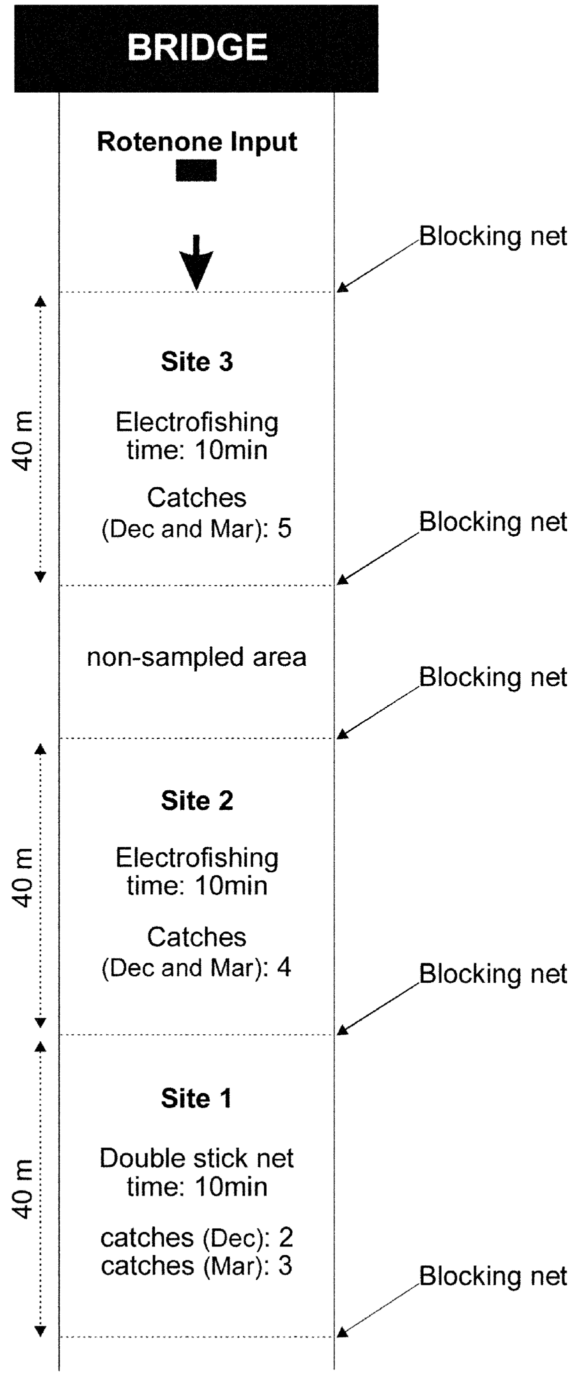

Figure 2. Scheme of three sites for sampling with information about gears, date and number of catches, locations of blocking nets and rotenone input.

1 and 2 canopy shade was due to densely growing trees and shrubs. The small canopy area in site 3 resulted from high grass growing along the right and partially along the left banks. A gap in sampling between sites 2 and 3 was a result of clumps of shrubs densely growing in the streambed (Fig. 2). Sampling in sites 1 and 2 was made difficult by three and two snags, respectively, as well as by overhanging shrubs branches.

Bathymetric maps constituted a background for the description of site morphologies, i.e. the profile of the bottom (proportion of pools and riffles) and then served to precisely determine the volume of water, which was necessary to properly apply rotenone and its antitoxicant in this study. Water depth was measured at 5 cm intervals along transects 5 m apart established across the stream and used to construct isobaths. Bottom structure and velocity were also recorded along these transects and other parameters were measured at the beginning of a given site. The sites' morphology and water characteristics are included in Table 1. Small differences in water parameters are noticeable only between dates of sampling. Sites' area, water volume, and width also fluctuated, but the respective differences between sites (also those of seasons) were certainly too insignificant to influence sampling efficiency in such a small stream. On December 16, 1996 and March 25, 1997 discharge amounted to 18 and 27 $l^{-1}s^{-1}$, respectively.

Besides the sampling occasions, we additionally visited our experimentally investigated reach of the Taquaral Stream 16 times between March 30, 1996 and June 15, 1998. We always then measured water temperature, conductivity, dissolved oxygen, pH, and averages of these parameters with 95% CL were: 23.25±3.21 °C, 31.81±4.15 μS cm^{-1}, 8.24±0.66 ml O_2 l^{-1}, and 6.89 (6.76–7.06), respectively. For pH the values were anti-logged, averaged and then back-transformed. Note the small and low variability of most of these parameters.

Material and sampling methods

A total of 4378 fish specimens identified to 34 taxa were collected and their full scientific names and their position in the water column are given in Table 2; in other tables we only use their abbreviations. Benthic species (20) dominated over pelago-benthic ones (13), and only one representative of the pelagic (open water) was recorded. This is important information for the sampling procedure because fish occurring in the water column try to escape from the noise at the site, while benthic ones hide in the nearest refuges, which, however, does not prevent their being effectively captured by an electric field, for example, in a small stream (Penczak, 1994).

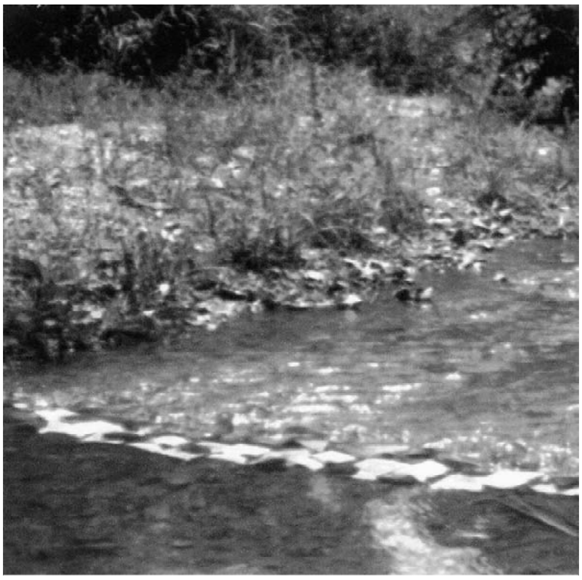

Figure 3. Perforated plastic sacks containing salt distributed across the river bed above the upstream end of site 3.

During sampling a stop net (5 mm bar mesh) was always placed at the upstream and downstream limit of each site (Fig. 2). We used two gears for collecting fish: a double stick net (Brandt, 1984) in site 1 and electric fishing in sites 2 and 3. Successive catches (2–5) per constant unit of effort (CPUE) were applied in the case of both gears (Fig. 2). In the case of sampling with the double stick net (DSN) one man who was operating the gear waded for 3–4 m along the river keeping the net close to the bottom and then rapidly turned to a bank; this operation was repeated several times during each sampling. The other one, using a pole, scared fish away from undermined banks and other hiding places, driving them into DSN. The whole net was 2 meters wide (mesh size = 0.5 cm, height = 1.5 m) and its sides ended with poles to which it was fixed. However, water current was usually too strong, as in our case, to operate it fully stretched by a moderately strong person; consequently, it was partially reeled in on the poles to obtain a 1.2 m wide operating width.

In the case of electrofishing, also two people parallely waded upstream along this narrow stream and electrofished with 40 cm diameter anode-dipnets (EF) for a constant effort and the whole width of the river

Table 1. Physical and chemical characteristics of sites in the Taquaral Stream (see text for further information)

Parameters	Site 1		Site 2		Site 3	
	December	March	December	March	December	March
Area (m^2)	111.5	138.0	134.0	92.4	112.0	119.5
Volume (m^3)	16.7	34.6	34.3	21.3	10.1	16.2
Mean width (m)	2.0	2.3	1.5	1.4	1.8	1.9
Mean depth (m)	0.15	0.25	0.24	0.20	0.09	0.13
Velocity (m s^{-1})	0.31	0.46	0.33	0.47	0.54	0.46
Substratum: mud (%)	10	10	10	5	5	5
Sand (%)	25	20	50	55	10	10
Gravel (%)	30	45	30	30	40	40
Pebbles (%)	30	20	10	10	40	40
Rock (%)	5	5	0	0	5	5
Water temperature (°C)	29.0	23.0	29.0	23.0	29.0	23.0
pH	7.12	6.84	7.11	6.84	7.11	6.84
O_2 (ml l^{-1})	7.56	7.80	7.56	7.90	7.70	7.90
Conductivity (μS cm^{-1})	41.0	32.0	41.0	32.0	42.0	32.0

was sampled by this method (Mahon et al., 1979; Penczak, 1981; Penczak & Molinski, 1984; Agostinho & Penczak, 1995). Full-wave rectified current was taken from a 3 kW generator with an output of 220 V, and 1.5-2.5 A at the dipnets. Because the water displayed a low conductivity (Table 1), several plastic, perforated sacks containing common salt were immersed in it (Fig. 3). The number of holes in the sacks was increased gradually to obtain a suitable level of conductivity. During sampling conductivity was held within a range of 150–200 μS cm^{-1}, which is sufficient for this purpose (Penczak et al., 1997a), and monitored continuously with a YSI 3800 Water Quality Logging System (U.S.A.). The stunned fish caught in the stop nets were collected after every catch and added to the total of the used gear. The number of fish caught in the stop nets was low and constituted, on average, 15% of the value that resulted from the application of a respective gear at a given site (maximum value was 21%). This was an effect of the large dip-net electrodes as well as the water salting (Penczak et al., 1997a).

After sampling the three sites with gears on a given day, rotenone was pumped to the Taquaral Stream, 2 m upstream of the blocking net of site 3 (Fig. 2). Rotenone dilution was calculated after Davies & Shelton (1983) and its level in the water was maintained for 1 h. Potassium permanganate was pumped below the blocking net downstream from site 1 simultaneously with the toxicant and for 15 min longer to detoxify the rotenone and no dead fish were seen downstream of the sampled sites. Fish caught with rotenone were counted and weighed separately from those caught by the other two methods.

All fish were anaesthetised (MS-222 – tricaine methanesulfonate) and then fixed in 4% formalin, because their identification in the field was rarely possible. In the laboratory, fish from each catch were separately identified, counted and weighed.

Data analysis

The Zippin maximum-likelihood graphical method for 2, 3, 4 or 5 catches (Zippin, 1956, 1958) was used for estimating density (*N*). When the method was not applicable (single fish specimens captured, or specimens absent in the first catch or fish number not decreasing in consecutive catches) fish caught with a gear plus those caught by rotenone were treated as the total number. Estimated value of *N* (fish number) and $\hat{p}$ (probability of capture in the *i*th sample) which corresponds to a value of *R* to be calculated for a given number of catches was read from a proper graph included in the cited papers. Estimates of (1– q^k) may be obtained from another graph included in the cited papers also. With the aid of these graphs, the procedure for obtaining an estimate of *N* is as follows:

Table 2. Mean body weight (w in g) of single taxa at three sites in two terms of sampling at the Taquaral Stream. Explanations: w_g is calculated on the basis of fish collected by gears, and w_r by rotenone, b – benthic, pb – pelagic-benthic, p – pelagic species

No.	Species	Site 1				Site 2				Site 3			
		December		March		December		March		December		March	
		w_g	w_r	w_g	w_r	w_g	w_r	w_g	w_r	w_g	w_r	w_g	w_r
1	*Apareiodon affinis*, b				1.28	2.71	3.52			4.44			5.52
2	*Apareiodon ibitiensis*, b	1.03	3.11	1.19		1.11	2.12	3.11	1.71	2.05		2.32	1.49
3	*Apareiodon piracicabae*, b	2.51	2.42	2.28	2.54	2.12	1.90	2.85	2.93	1.79		2.39	1.88
4	*Aspidoras fuscogutattus* b									1.53		0.35	
5	*Astyanax bimaculatus*, pb	3.29	4.15	4.86	6.49	3.94	4.12	6.07	6.21	3.29		5.21	5.45
6	*Astyanax eigenmanniorum*, pb		6.47			1.89	6.38	1.52	1.20	1.06	1.57	1.95	
7	*Astyanax fasciatum*, pb				8.95								
8	*Astyanax scabripinnis*, pb	0.60	11.59			10.55	12.48	10.69		10.87	2.34	4.72	
9	*Astyanax* sp., pb							0.09					
10	*Bryconamericus* sp., b		8.67			0.35	5.41			0.84			
11	*Bryconamericus* sp. 3, b	0.60	0.86	0.65	0.53	0.81	0.46	0.71	0.72	0.68	0.69	0.86	0.73
12	*Bryconamericus stramineus*, b	0.89	0.67	0.73		0.67		0.80	0.41	0.52			
13	*Cetopsorhamdia iheringi*, b	1.89	2.91							2.12	2.47	2.28	1.84
14	*Characidium* aff. *zebra*, b	7.28		0.61				2.29				3.73	
15	*Cichlasoma paranaense*, b		39.30	9.84	11.41	8.81		19.96	14.02	7.25	11.40	8.58	
16	*Cyphochorax modestus*, b											17.01	
17	*Eigenmannia* sp., pb								22.91				
18	*Gymnotus carapo*, b		17.11		35.04	13.31	23.20	10.18	60.53	9.76	8.88	6.56	
19	*Hasemania hanseni*, pb				0.15			0.21					
20	*Hoplias* aff. *malabaricus*, pb			88.10				72.22	55.37				
21	*Hypostomus regani*, b	14.49				43.14					3.00		
22	*Hypostomus* sp., b		30.77		3.74	66.08	69.27	10.52	33.63	2.94		7.02	5.58
23	*Lebistes reticulatus*, pb	0.44	0.56	0.27	0.19	0.19		0.12	0.38	0.30	0.27	0.26	0.28
24	*Leporinus amblyrhynchus*, b				6.29	30.33	24.06	14.77	8.63			3.71	
25	*Nannorhamdia schubarti*, b									2.26			
26	*Oligosarcus pintoi*, p		18.85		10.35	19.86	17.89	8.67					
27	*Orechromis niloticus*, pb						32.97	60.84	54.72			3.07	
28	*Piabina argentea*, pb	4.36	4.91	1.50	4.31	6.58	3.88	3.87		1.92	4.30	2.95	3.39
29	*Pimelodella gracilis*, b						3.96						
30	*Pimelodus maculatus*, pb			6.19	9.31			7.88	10.74			7.83	9.41
31	*Rhamdia quelen*, pb		67.33	18.56	5.41	2.82	33.83		31.61	4.60			
32	*Steindachnerina insculpta*, b					26.92	23.00						
33	*Steindachnerina* sp., b				13.38			22.03	5.47				
34	*Trichomycterus* sp., b	3.74								2.05			
	Mean	1.58	8.34	2.47	6.94	4.03	8.23	4.55	20.80	1.64	1.91	2.88	2.94

1. Calculate:

$$T = \Sigma_{i=1}^{k} yi,$$

then

$$R = \frac{\Sigma_{i=1}^{k}(i-1)yi}{T}$$

2. Find estimate of $(1–q^k)$ corresponding to R from an appropriate graph

3. Calculate:

$$N = \frac{T}{(1-\hat{q}^k})$$

4. Symbols' explanations: k is catches number, y_i is number of fish captured during the ith catch.

For N variance is available, which allows to calculate 95% CL = 1.96 $\sqrt{V[N]}$

$$V[N] = \frac{N(1-\hat{q}^k)\hat{q}}{(1-\hat{q}^k)^2 - (\hat{p}^k)^2 q^{k-1}}$$

Table 3. Number of taxa recorded at three contiguous sites of the Taquaral Stream by two different gears and rotenone (in brackets number of species as percentage). Explanations: dsn – double stick net, ef – electric fishing

Number of species recorded by:	Site 1(dsn)		Site 2 (ef)		Site 3 (ef)	
	December	March	December	March	December	March
Gears (A)	12 (63.2)	12 (60)	19 (90.5)	21 (91.3)	19 (95)	18 (94.7)
Rotenone	16 (84.2)	16 (80)	17 (81)	17 (73.9)	9 (45)	10 (52.6)
Rotenone only (B)	7 (36.8)	8 (40)	2 (9.5)	2 (8.7)	1 (5)	1 (5.3)
A + B	19 (100)	20 (100)	21 (100)	3 (100)	20 (100)	19 (100)

The equation used for calculating the biomass (B) was: $B = {}^{g}BN/{}^{g}N$, where ${}^{g}B$ is the total weight of fish caught by a gear, and ${}^{g}N$ is the total number of fish caught by a gear.

Results

Qualitative analysis of fishing results showed that the numbers of taxa in the three neighbouring sites somewhat varied (Table 3). In site 2, with difficult conditions for sampling by EF, two additional species were discovered by the toxicant on both sampling occasions, in contrast to site 3, where only one additional species enriched the list of taxa. However this latter site was open, with a poor riparian vegetation zone. In site 1, which was sampled with the net in December and March, 6 and 8 taxa were collected by rotenone exclusively, which determined 31.6 and 40% of the total species number, respectively. Differences in number of species recorded with rotenone and then compared with those caught by DSN (Table 3) were statistically significant. The Chi-square and Fisher exact tests revealed differences at the probability levels $p = 0.02$, and $p = 0.034$, respectively ('2 × 2 table'). The number of taxa obtained by rotenone and EF did not differ significantly by the same tests.

Fish taxa were recorded by a given gear, their number and weight, and rotenone catches, calculated density (N), biomass (B), upper 95%CL for both values, and Zippin statistics ($\hat{p}$). 'Total' (bottom row) in these tables contains actual numbers of fish caught by both methods (gear and rotenone). Parameters 'Error for N (%)' and 'Error for B (%)' contain differences in plus or in minus between fish collected by a gear plus rotenone and estimated density or biomass values. For both parameters the mean values were calculated.

A preliminary comparison of results from Tables 4–5 (DSN) with Tables 6–9 (EF) shows that the Zippin

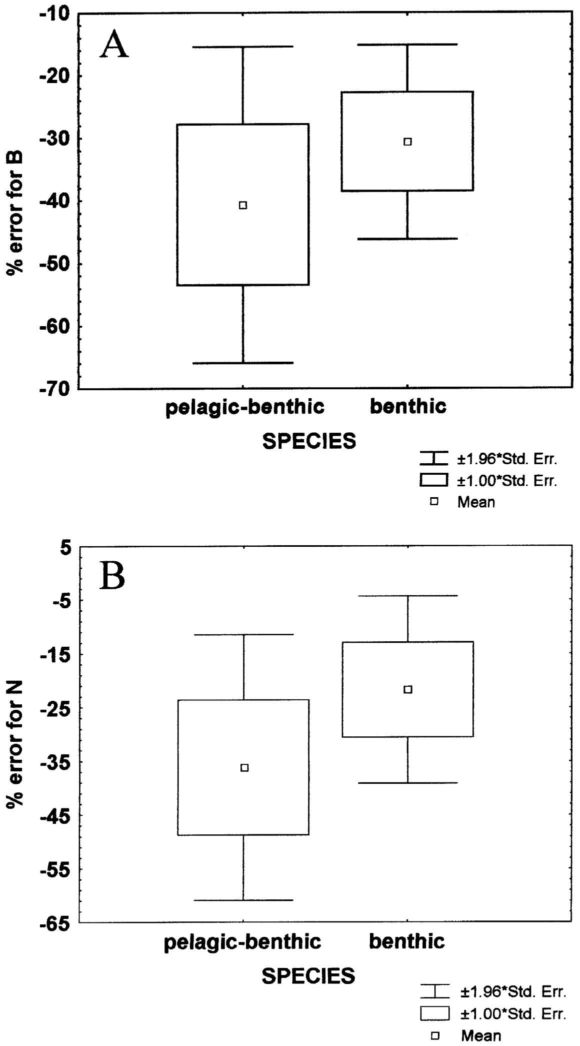

Figure 4. Underestimation measured as percentage difference between calculated density (A) and biomass (B) and real number of fish collected (electrofishing + rotenone). pb – pelagic-benthic taxa, b – benthic taxa.

Table 4. Number (numerator) and standing crop in g (denominator) obtained from site 1 in the Taquaral Stream on December 16, 1996 by successive removal catches (C_1-C_n) and rotenone. Site was sampled with a double stick net. Explanations: *N* is estimated density with 95% CL, B is estimated standing crop with 95% CL, $\hat{p}$ is catch efficiency (Zippin model), symbols b and pb are explained in Table 2, [a] in this case upper 95% CL is larger than a real value, [g] sampled by gear, [r] sampled by rotenone (see text for farther explanations)

Species	C_1	C_2	Total	Rotenone	*N*	Upper	$\hat{p}$	% of error	B	Upper	% error
	${}^gN$ / ${}^gB$	${}^gN$ ${}^gB$	${}^gN$ ${}^gB$	${}^rN$ /${}^rB$		95% CL		for *N*		95% CL	for B
A. bimaculatus, pb	9 / 28.31	1 / 4.55	10 / 32.86	83 / 344.04	10	11	0.88	–89.2	32.86	36.15	–91.3
A. eigenmanniorum, pb				5 / 32.36							
A. ibitiensis, b	9 / 9.51	3 / 2.87	12 / 12.38	10 / 31.05	14	19	0.66	–36.4	14.44	19.60	–66.8
A. piracicabae, b	10 / 26.75	3 / 5.94	13 / 32.69	57 / 138.19	14	19	0.69	–80.0	32.21	47.78	–81.2
A. scabripinnis, pb	2 / 1.19		2 / 1.19	57 / 660.37							
B. stramineus, b	4 / 2.94	1 / 1.52	5 / 4.46	8 / 5.39	5	7	0.74	–61.5	4.46	6.24	–54.7
Bryconamericus sp., b				2 / 17.34							
Bryconamericus sp 3, b	55 / 35.44	37 / 19.97	92 / 55.41	59 / 50.58	171	296	0.32	+13.2	102.99	178.28[a]	–2.8
C. iheringi, pb		1 / 1.89	1 / 1.89	3 / 8.72							
C. paranaense, b				4 / 157.21							
C. zebra, b		1 / 7.28	1 / 7.28								
G. carapo, b				15 / 256.70							
H. regani, b	2 / 28.98		2 / 28.98								
Hypostomus sp., b				24 / 738.45							
L. reticulatus, pb	2 / 0.87		2 / 0.87	2 / 1.11							
O. pintoi, p				1 / 18.85							
P. argentea, pb	11 / 54.89	4 / 10.50	15 / 65.39	18 / 88.33	17	25	0.63	–48.5	74.11	108.98	–51.8
R. quelen, b				6 / 403.99							
Trichomycterus sp., b		1 / 3.74	1 / 3.74								
Total/Mean	104 / 188.88	52 / 58.26	156 / 247.14	354 / 2952.68			–60.5			–58.1	

method could have been more frequently calculated in sites 2 and 3. This is the evidence that electric fishing in a small tropical stream is more effective than the other gear that was used.

Both in terms of fish number and biomass (*N*, B) at a given site (Tables 4–9), the largest differences between captured fish obtained using a fishing gear and the gear plus rotenone were recorded in site 1, which was sampled with DSN. Underestimation calculated for *N* and B amounts, on average, to 60% there. On the contrary, in sites 2 and 3, the mean amounted to 33 and 23%, respectively, although the sites much physically differed, because the former was difficult to access while the latter was easily accessible. For separate sites, upper 95% CL for *N* and B were sometimes close to or larger than the real number and biomass of fish caught (Table 9).

Perceiving large differences among taxa in fishing efficiency measured as percentage between *N* or B and real (gear+rotenone) catches (% error for *N* and B), we checked if they could have been influenced by various swimming capacity of various groups of these taxa. For pelagic–benthic taxa the mean underestimations for N and B, in comparison with benthic taxa, were 14 and 12% higher, respectively (Fig. 4), but because of a large dispersion of results' variances the values were insignificant (Mann–Whitney test, $p = 0.49$). Also, the averages of the efficiency of the first catch, $\hat{p}$ (from the Zippin model), were insignificantly different between pelagic–benthic and benthic taxa.

In response to the problem that large fish are more easily than small fish caught by gears, we present, in Table 2, the mean body weight of every species on each sampling occasion, which was collected by both gears (w_g) and rotenone (w_r). When we inspect the means calculated on the dates of sampling (Table 2) we can see that w_r are larger than w_g, without exception. Also, using all data for calculating grand means, we obtained $w_r = 9.58$ g, which is greater than $w_g = 8.38$ g, although the *T*-test used for dependent samples (normal distribution calculated) revealed insignificant differences ($p = 0.30$). The data from Table 2 analysed separately for benthic and pelagic–benthic species on the two sampling periods show that means for fish caught by rotenone are slightly bigger (with one exception) but pelagic–benthic taxa in December and

Table 5. Number and standing crop obtained from site 1 in the Taquaral Stream on March 25, 1997. Site was sampled with a double stick net (see Table 4 for symbols' explanations)

Species	C_1 ${}^gN$ / ${}^gB$	C_2 ${}^gN$ / ${}^gB$	C_3 ${}^gN$ / ${}^gB$	Total ${}^gN$ / ${}^gB$	Rotenone ${}^rN$ / ${}^rB$	N	Upper 95% CL	$\hat{p}$	% error for N	B	Upper 95% CL	% error for B
A. affinis, b					1 / 1.28							
A. bimaculatus, pb	9 / 44.18	2 / 9.71	3 / 14.11	14 / 68.00	120 / 779.39	16	22	0.49	–88.1	77.71	106.86	–90.8
A. fasciatus, pb					11 / 98.42							
A. ibitiensis, b		1 / 1.90		1 / 1.90								
A. piracicabae, b	3 / 7.23	6 / 13.01	3 / 7.10	12 / 27.34	24 / 60.93							
B. stramineus, b		3 / 2.20		3 / 2.20								
Bryconamericus sp 3, b	42 / 27.99	22 / 13.68		64 / 41.67	45 / 23.84	66	69	0.70	–39.4	42.97	44.93	–34.4
C. paranaense, b	1 / 9.84			1 / 9.84	2 / 22.81							
C. zebra, b	1 / 0.61			1 / 0.61								
C. carapo, b					15 / 525.62							
H. hanseni, pb					1 / 0.15							
H. malabaricus, pb		1 / 88.08		1 / 88.08								
Hypostomus sp, b					3 / 11.22							
L. amblyrhynchus, b					2 / 12.58							
L. reticulatus, pb	1 / 0.27			1 / 0.27	5 / 0.97							
O. pintoi, p					1 / 10.35							
P. argentea, pb	1 / 2.09	3 / 13.00	14 / 11.98	18 / 27.07	9 / 38.83							
P. maculatus, pb			1 / 6.19	1 / 6.19	26 / 242.18							
R. quelen, b	1 / 18.56			1 / 18.56	5 / 27.07							
Steindachnerina sp, b					3 / 40.14							
Total/Mean	59 / 110.77	38 / 151.58	21 / 39.38	118 / 291.73	273 1895.78				–63.8			–62.8

Table 6. Number and standing crop obtained from site 2 in the Taquaral Stream on December 16, 1996. Site was sampled with electric fishing (see Table 4 for symbols' explanations)

Species	C_1		C_2		C_3		C_4		Total		Rotenone		N	Upper	$\hat{p}$	% error	B	Upper	% error
	^{g}N	^{g}B	^{g}N	^{g}B	^{g}N	^{g}B	^{g}N	^{g}B	^{g}N	^{g}B	^{r}N	^{r}B		95% CL		for N		95% CL	for B
A. affinis, b	9 /	25.55	1 /	2.19	1 /	2.11			11 /	29.85	3 /	10.55	11	11	0.77	–21.4	29.85	29.85	–26.1
A. bimaclatus, pb	14 /	51.75			6 /	27.43	11 /	43.11	31 /	122.29	102 /	419.79	270	2900	0.03	+103.0	1065.11	11440.0	+96.5
A. eigenmanniorum, pb	10	/ 15.00			3 /	9.54			13 /	24.54	30 /	191.39	13	140.65	–69.8	24.54	26.43	–88.6	
A. ibitiensis, b	9	/ 10.72	3 /	5.14	4 /	3.14	4 /	3.23	20 /	22.23	18 /	38.18	30	169[a]	0.24	–21.1	33.35	187.84[a]	–44.8
A. piracicabae, b	66	/ 135.37	45 /	105.64	18 /	35.59			129 /	276.60	195 /	370.30	134	140	0.56	–58.6	287.32	300.19	–55.6
A. scabripinnis, pb	2	/ 22.73	2 /	13.94	7 /	75.25	7 /	78.17	18 /	190.09	39 /	486.86							
B. stramineus, b	3 /	2.78	3 /	1.35			1 /	0.56	7 /	4.69			8	12			5.36	8.04	
Bryconamericus sp., b					1 /	0.35	1 /	0.35	1 /	5.41									
Bryconamericus sp3, b	109 /	95.67	42 /	29.31	26 /	18.24	1 /	0.42	178 /	143.67	56 /	25.59	183	188	0.60	–21.8	147.71	151.74	–12.7
C. paranaense, b			2 /	1.75	2 /	33.47			4 /	35.22									
G. carapo, b	6 /	113.25	3 /	6.51					9 /	119.76	12 /	278.45	9	10	0.73	–57.1	119.76	133.07	–69.9
H. regani, b	2 /	141.74	1 /	24.77			1 /	6.05	4 /	172.56			5	10	0.34		215.70	431.40	
Hypostomus sp., b	1 /	124.56	2 /	66.38	1 /	73.38	4 /	264.32	27 /	1870.16									
L. amblyrhynchus, b	1 /	18.78			1 /	36.34	1 /	35.86	3 /	90.98	2 /	48.12							
L. reticulatus, pb	3 /	0.63			4 /	0.78	1 /	0.08	8 /	1.49			26	165			4.84	30.73	
O. niloticus, pb											2 /	65.94							
O. pintoi, p	1 /	19.86							1 /	19.86	2 /	35.77							
P. argentea, pb	9 /	61.03	3 /	17.58	2 /	13.52			14 /	92.13	8 /	31.07	14	16	0.63	–36.4	92.13	105.29	–24.4
P. gracilis, b											1 /	3.96							
R. quelen, b	1 /	2.82							1 /	2.82	5 /	169.14							
S. insculpta, b	3 /	102.45	1 /	32.35	4 /	106.69	2 /	27.67	10 /	269.21	6 /	137.98							
Total/Meam	249 /	944.69	108 /	306.91	80 /	432.67	29 /	195.15	466 /	1882.66	509 /	4188.66				–26.2			–32.2

Table 7. Number and standing crop obtained from site 2 in the Taquaral Stream on March 25, 1997. Site sampled with electric fishing (see Table 4 for symbols explanations)

Species	C_1		C_2		C_3		C_4		Total		Rotenone		N	Upper 95% CL	$\hat{p}$	% error for N	B	Upper 95% CL	% error for B
	$^gN/$	^{g}B	$^gN/$	^{g}B	$^gN/$	^{g}B	$^gN/$	^{g}B	$^gN/$	^{g}B	$^rN/$	^{r}B							
A. bimaculatus, pb	54 /	339.97	12 /	66.63	5 /	30.40	10 /	54.80	81 /	491.80	30 /	186.29	85	90	0.55	–23.4	516.09	546.44	–23.9
A. eigenmanniorum, pb	1 /	1.96			1 /	1.07			2 /	3.03	2 /	2.39							
A. ibitiensis, b	12 /	36.16	2 /	8.49	2 /	7.48	2 /	3.89	18 /	56.02	6 /	10.24	19	22	0.53	–20.8	59.13	68.47[a]	–10.8
A. piracicabae, b	107 /	306.65	18 /	49.11	7 /	17.18	7 /	23.53	139 /	396.47	31 /	90.74	140	143	0.70	–17.6	399.32	407.88	–18.0
A. scabripinnis, pb	1 /	2.98			3 /	35.82	1 /	14.67	5 /	53.47									
Astyanax sp., pb					1 /	0.09			1 /	0.09									
B. stramineus, b			2 /	1.00	1 /	1.41			3 /	2.41	1 /	0.41							
Bryconamericus sp3, b	46 /	30.97	21 /	17.66	14 /	10.98	12 /	6.38	93 /	65.99	20 /	14.37	108	124[a]	0.39	–4.4	76.63	87.99[a]	–4.6
C. paranaense, b			2 /	55.05	2 /	24.77			4 /	79.82	3	42.05							
C. zebra, b	2 /	4.58							2 /	4.58									
Eigenmannia sp., pb											1 /	22.91							
G. carapo, b	6 /	52.89			1 /	45.44	3 /	3.50	10 /	101.83	37 /	2239.53	14	26	0.28	–70.2	142.56	264.76	–93.9
H. hanseni, pb					1 /	0.21			1 /	0.21									
H. malabaricus, pb	1 /	48.45	2 /	168.21			3 /	216.66	4 /	221.47									
Hypostomus sp., b	3 /	31.93					1 /	10.15	4 /	42.08	10 /	336.25	4	6	0.48	–71.4	42.08	63.12	–88.9
L. amblyrhynchus, b	1 /	11.06	1 /	18.47					2 /	29.53	1 /	8.63							
L. reticulatus, pb	1 /	0.34	4 /	0.30	1 /	0.06			6 /	0.70	3 /	1.15							
O. niloticus, pb	2 /	121.68	2 /	121.68	3 /	164.16													
O. pintoi, p					1 /	8.67			1 /	8.67									
P. argentea, pb	5 /	19.89	1 /	1.63					6 /	21.52			6	6	0.85	0	21.52	21.52	0
P. maculatus, pb	6 /	42.64	3 /	28.26					9 /	70.90	28 /	300.58	9	10	0.73	–75.7	70.90	78.78	–80.9
R. quelen, b											11 /	347.75							
Steindachnerina sp, b	/		1 /	22.03					1 /	22.03	1 /	5.47							
TotalMean	248 /	1052.15	67 /	268.63	42 /	351.79	36 /	116.92	393 /	1789.49	192 /	3994.39				–35.4			–40.1

Table 8. Number and standing crop obtained from site 3 in the Taquaral Stream on December 16, 1996. Site sampled with electric fishing (see Table 4 for symbols explanations)

Species	C_1		C_2		C_3		C_4		C_5		Total		Rotenone		N	p	% error	B	Upper	% error
	^{g}N /	^{g}B	^{g}N /	^{g}B	^{g}N /	^{g}B	^{g}N /	^{g}B	^{g}N /	^{g}B	^{g}N /	^{g}B	^{r}N /	^{r}B			for N	B	95% CL	for B
A. affinis, b	10 /	52.25	2 /	3.00					1 /	2.41	13 /	57.66			13	57.66	62.10			
A. bimaculatus, pb	50 /	161.55	9 /	36.24	2 /	5.03	5 /	14.56			66 /	217.38			66		217.38	220.67		
A. eigenmanniorum, pb	8 /	6.91	1 /	0.83			1 /	2.12	4 /	4.95	14 /	14.81	8 /	12.57	18	0.25	–18.2	19.04	31.74[a]	–30.5
A. fuscogutattus, b			1 /	2.39	1 /	0.67					2 /	3.06								
A. ibitiensis, b	79 /	196.82	36 /	55.58	18 /	41.55	14 /	17.43	14 /	19.33	161 /	330.71			175			359.47	384.12	
A. piracicabae, b	186 /	348.88	88 /	166.56	74 /	123.01	32 /	43.70	12 /	16.49	392 /	701.46				415			742.62	767.67
A. scabripinnis, pb	2 /	21.73									2 /	21.73	11 /	25.70			–81.8			–15.4
B. stramineus, b			3 /	1.66	2 /	0.94					5 /	2.60								
Bryconamericus sp., b					2 /	1.80			2 /	1.55	4 /	3.35								
Bryconamericus sp 3., b	181 /	139.41	103 /	68.58	72 /	46.76	43 /	22.87	34 /	16.75	433 /	294.37	88 /	60.99	490	0.35	–6.0	333.12	352.84	–6.3
C. iheringi, pb			2 /	3.41	1 /	1.98			1 /	0.98	4 /	6.37	1 /	2.47						
C. paranaense, b	2 /	2.11	3 /	52.92	2 /	1.60	1 /	1.40			8 /	58.03	6 /	68.38	9	0.32	–35.7	65.28	101.55	–48.4
G. carapo, b	6 /	11.14	2 /	138.52	5 /	7.47	2 /	4.52	2 /	4.23	17 /	165.88	10 /	88.80	25	0.21	–7.4	243.94	439.09	–4.2
H. regani, b													2 /	6.01			–100.0			–100.0
Hypostomus sp., b	2 /	5.80	1 /	2.54	2 /	6.69	1 /	2.64	1 /	2.91	7 /	20.58			14			41.16	152.88	
L. reticulatus, pb	21 /	5.97	9 /	2.66	6 /	1.67	5 /	1.82	41 /	12.12	34 /	9.14 51	0.28	–32.0	15.08	19.81	–29.1			
N. schubarti, pb	3 /	6.88	1 /	2.17							4 /	9.05	4			9.05	9.05			
P. argentea, pb	9 /	17.97	3 /	5.46	1 /	1.44	1	/ 2.06	1 /	1.82	15 /	28.75	13 /	55.89	15	0.51	–46.4	28.75	32.58	–66.0
R. quelen, b	2 /	9.17									2 /	9.17								
Trichomycterus sp., b									1 /	2.05	1 /	2.05								
Total/Mean	561 /	986.59	255 /	542.68	191 /	241.60	106 /	112.97	78 /	75.29	1191 /	1959.13	173 /	329.95			–40.9			–37.5

Table 9. Number and standing crop from site 3 in the Taquaral Stream on March 25, 1997. Site sampled with electric fishing (see Table 4 for symbols' explanations)

Species	C_1		C2		C_3		C_4		C_5		Total		Rotenone		N	$\hat{p}$	Upper 95% CL	% error for N	B	Upper 95% CL	% error for B
	^gN	^{g}B	^gN	^{g}B	^gN	^{g}B	^gN	^{g}B	^gN	^{g}B	^gN	^{g}B	^rN	^{r}B							
A. affinis, b													1 /	5.52							
A. bimaculatus, pb	47 /	256.40	17 /	109.93	7 /	38.88	5 /	22.79	2 /	7.51	78 /	406.29	15 /	81.79	79	0.56	82	–15.1	411.5	427.13	–15.7
A. aigenmanniorum, pb	2 /	3.90									2 /	3.90									
A. fuscogutattus, pb									1 /	0.35	1 /	0.35									
A. ibitiensis, b	10 /	29.99	8 /	14.77	6 /	12.08	1 /	2.39	1 /	1.11	26 /	60.34	7 /	10.42	28	0.41	33	–15.2	64.98	76.59[a]	–8.2
A. piracicabae, b	105 /	269.21	42 /	92.64	32 /	78.84	9 /	17.97	16 /	29.03	204 /	487.69	21 /	39.57	216	0.44	226[a]	–4.0	516.38	540.28[a]	–2.1
A. scabripinnis, pb											1 /	4.72				1 /	4.72				
Bryconamericus, sp 3, b	43 /	40.93	33 /	27.59	12 /	8.73	10 /	7.78	4 /	2.24	102 /	87.27	12 /	8.78	109	0.42	118[a]	–4.4	93.26	100.96[a]	–2.9
C. iheringi, pb			1 /	2.28							1 /	2.28	1 /	1.84							
C. modestus, b			1 /	17.01							1 /	17.01									
C. paranaense, b	1 /	12.26					1 /	4.90			2 /	17.16									
C. zebra, b	1 /	3.73									1 /	3.73									
G. carapo, b	4 /	29.35	3 /	16.80	2 /	12.87	2 /	13.11			11 /	72.13			12		17		78.68	111.47	+62.3
Hypostomus sp., b	5 /	44.90	5 /	29.03	3 /	45.93	3 /	3.46	3 /	5.35	19 /	133.33	4 /	22.31	36[a]	0.14	89[a]	+56.5	252.62[a]	624.55[a]	
L. amblyrhynchus, b	1 /	3.71									1 /	3.71									
L. reticulatus, pb	5 /	1.35	5 /	1.50	3 /	0.46			2 /	0.62	15 /	3.93	9 /	2.55	18	0.32	24	–25.0	4.72	6.29	–27.2
O. niloticus, pb									1 /	3.07	1 /	3.07									
P. argentea, pb	1 /	4.35	1 /	0.55	1 /	5.39			1 /	1.51	4 /	11.80	1 /	3.39							
P. maculatus, pb	3 /	21.11	2 /	20.84	1 /	6.47	1 /	6.34			7 /	54.79	5 /	47.07	7	0.43	10	–41.7	54.79	78.27	–46.2
Total/Mean	228	/ 721.19	118 /	303.72	84 /	209.65	33 /	83.49	31 /	55.45	477 /	1373.50	76 /	223.24				–8.1			–6.7

Table 10. The total number (TN) and total biomass (TB in g) of fish collected by gears, gears plus rotenone (r) , estimated from Zippin model, Z (numerator) is density estimated from Zippin model, Z (denominator) is upper 95% CL for Z, and percent error for Z (% for Z). Explanation: dsn is double stick net, ef is electric fishing

Parameters	Site 1 (dsn)				Site 2 (ef)				Site 3 (ef)			
	December		March		December		March		December		March	
	TN	TB	TN	TB	TN	TB	TN	TB	TN	TB	TN	TB
Gears	156	247	118	292	466	1879	393	1790	1191	1959	477	1374
Gears + *r*	510	3200	391	2188	975	6068	585	5784	1364	2289	553	1597
Z	211/263	257/297	153/187	435/532	503/522	2205/2283	411/424	1919/1955	1291/1324	2029/2051	508/524	1428/1448
% for Z	–60.5	–60.2	–63.8	–62.6	–26.2	–32.2	–35.4	–40.1	–40.9	–37.5	–8.1	–6.7

Table 11. Spearman rank order correlations among the variables: $\hat{p}$ catchability efficiency from the Zippin model, Error-*N* is percentage of error for density calculated per site (*N*), Error-B is percentage of error for standing crop calculated per site (B), w_g is mean body weight of populations for fish collected by gears, w_r is mean body weight of populations for fish collected by rotenone, *N* is density, B is standing crop.

$\hat{p}$	–0.561***	–0.463**	0.074	0.089	–0.386*	–0.200
–0.561***	Error-*N*	0.952***	–0.279	–0.374*	0.732***	0.444**
–0.463**	0.952***	Error-B	–0.255	–0.416**	0.738***	0.498**
–0.074	–0.279	–0.0255	w_g	0.899***	–0.430**	0.380*
0.089	–0.374*	–0.416**	0.899***	w_r	–0.502**	0.231
–0.386**	0.732***	0.738***	–0.430**	–0.502**	*N*	0.603***
–0.200	0.444**	0.498**	0.380*	0.231	0.603***	B

* Marked probability level $p < 0.02$, ** for $p < 0.01$–0.001, *** for $p < 0.000$

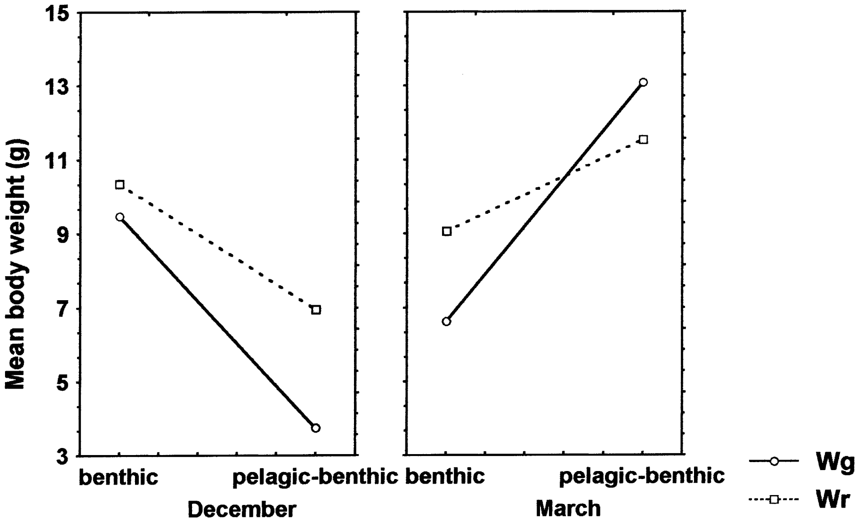

Figure 5. Mean body weight of fish collected by gears (w_g) and rotenone (w_r) on two sampling occasions calculated separately for pelagic-benthic taxa (pb) and benthic ones (b).

benthic taxa in March reversed the slope of these curves (Fig. 5). This phenomenon can be explained by calculated linear regressions w_g vs. w_r. In Figure 6B and C we can see that the appearance of 0+ fish in these terms disturbs fishing efficiency of both gears and rotenone; in Figure 6A and D the dominance of specimens of similar size resulted in better fitting of the data to the regression lines and much narrower 95% CL.

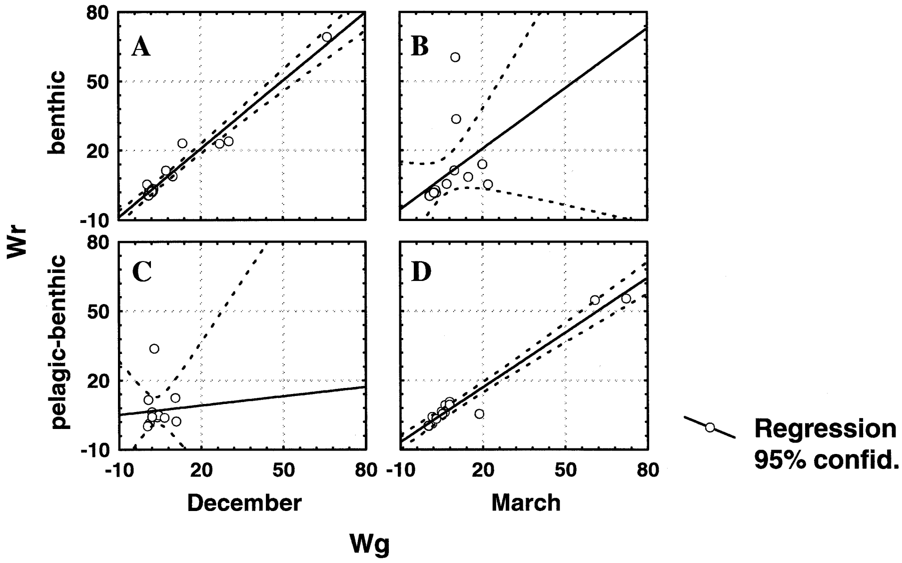

Figure 6. Regression (with 95% CL) for mean body of fish sampled by gears (w_g) and rotenone (w_r) separately for pelagic-benthic (pb), and benthic (b) taxa on two sampling occasions (see text for further explanations).

Discussion

For determining the list of species in a tropical stream with a low conductivity and difficult access to the riverbed, the use of different gears is recommended rather than a lethal toxicant (Rider et al., 1994). In our research we missed only one (site 3) or two species (site 2) on every occasion when sampling with EF (Table 3). At difficult for sampling site 2, *O. niloticus* was missed in December but was electrically fished in March, and only *P. gracilis* escaped our attention (Tables 6 and 7). Similarly, in site 3, only one species (*H. regani*) would have remained unrecognised if rotenone had not been used (Tables 8 and 9). Such small losses of rare species can be effectively reduced by sampling either in different seasons or by additional sites (Larimore, 1961), which is adequate for establishing species number in the present study.

Because error in estimating density and biomass was usually underestimation (on six sampling occasions) it produces a consistent problem (Table 4–9). This error was lower when a sampled site was easy for collecting stunned fish and respective confirmations are found in earlier papers on the subject (Cuinat, 1967; Mahon, 1980; Zalewski & Penczak, 1981; Zalewski, 1983; Casselman et al., 1990; Rider et al., 1994). The underestimation of density for EF was in the range of 41–8% there. In small rivers of the temperate zone, this value was lower and amounted to: (1) 22–11.1% in Sweden (Bohlin, 1977), (2) 20 and 21% in Canada and the U.S.A., respectively (Mahon, 1980; Rider et al., 1994), and 18.4–1.4% (Penczak, 1981) and 51–10% (Zalewski & Penczak, 1981) in two small catchments in Poland; a 51% underestimation of calculated density took place in sites greatly overgrown by macrophytes and containing immersed roots of numerous trees which shadowed the site and thus rendered fish catches more difficult. These are very important findings for researchers working on secondary fish production in rivers and then consequently calculating yield for anglers and commercial fishermen exploiting natural fish populations (Welcomme, 1985). This is especially important information for scientists applying bioenergetics models for calculating energy budgets or its compounds for riverine populations, because according to Hansen et al. (1993) estimated results 'also depend on accurate estimates of population sizes'.

Using a correlation matrix Mahon (1980) analysed which variables were positively or negatively significantly dependent on the mean weight of one fish in a sample, because according to his study the literary problem of size-selectivity which interacts between mean body weight and changing catchability was not synonymous. He concluded that 'size-selectivity was insignificantly associated with changing catchability. Other possible causes of this phenomenon must be sought'. In that paper he also stated that 'this unexpected lack of association indicates that changing catchability is not primarily caused by size- selectivity'. Rider et al. (1994) reached the more definite conclusion that 'size-selectivity was not evident as no significant correlation existed between mean length and mean weight at capture for each sampling interval'. They wrote that the size of fish caught by rotenone and electric fishing was similar, but in the figure of their paper we can see that in the vegetated site the biggest specimens were collected by rotenone while at an unvegetated one the biggest specimens were sampled by electric fishing.

Similarly as Mahon (1980), we found a significant correlation between w_g vs. estimated B and N (Table 10) as well as w_r vs. Error-N and Error-B. An essential difference was the lack of significant relationship between catchability efficiency ($\hat{p}$) and mean body weight in our research (Table 10); we do not think that a different method used by us for calculating fish density could cause these differences.

Using our data from Tables 6–9 we verified the dependence of mean weight of fish in the first catch/total catch obtained by EF on the mean weight of fish collected by rotenone/total catch, which in a paper by Zalewski (1983), based on riverine fish populations from Canada and Poland, were always significantly correlated. Both of these dependencies, and also for transformed data (log), were insignificant: both measured by the Spearman correlation applied in our study, and by the Pearson one applied by Zalewski (1983).

Perhaps we are not so enthusiastic about electric fishing as Rider et al. (1994) but in general we agree that the electric fishing catch-depletion method is less labour intensive and thus less costly, and fish do not have to be killed. Their suggestion that increased number of samples can positively improve sampling results is very convincing and we have already applied this approach in recent papers (Penczak & Jakubowski, 1990). We included DSN to this research because the method is still very popular in South America, particularly in Venezuela and Brazil, and the scientists of these countries believe it is the best method for sampling fish in small streams and they publish numerous studies based on this method in local journals.

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