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Evaluation of electrofishing efficiency in a stream under natural and regulated conditions

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Abstract – Sampling efficiency (p), estimated from the Zippin depletion model and the percentage of fish obtained during first runs (single-pass electrofishing), which is also named relative abundance (C_1), calculated as the ratio of C_1 to estimated density for a site (C_e), were analysed in five contiguous sites in a small lowland stream in Poland over 23 years. The sampled reach was unregulated during the first decade of the study period, but regulated by weirs and sluices in the latter 13 years. The sites were populated with 17 fish species during this period. Sampling efficiency p calculated for all species did not differ significantly between the five sites in any given year, between benthic and non-benthic species, or between the natural and regulated periods. Differences in p were only observed between some species. C_1 differed significantly between large and small species and, except for roach, was not dependent on the number of runs. Results indicate a high stability of both sampling indices in this small stream, despite changes in channel morphology after regulation: information which could be useful for future sampling research in streams.

Key words: Lowland stream / Natural / Regulated / Electrofishing efficiency / Relative abundance

Résumé – Evaluation de l'efficacité de la pêche électrique en rivière en conditions naturelles et en débit régulé. L'efficacité de l'échantillonnage (p), estimée à partir du modèle de Zippin et le pourcentage de poissons obtenu durant les premiers passages, appelé aussi abondance relative (C_1), calculée comme le rapport de C_1 à la densité estimée pour un site (C_e), ont été analysés en cinq sites contigus, dans une petite rivière de plaine, en Pologne, sur une période de 23 ans. Le bief échantillonné était non-régulé durant les dix premières années de l'étude, puis régulé au moyen de barrages et chenaux, les treize années suivantes. Les sites étaient peuplées de 17 espèces de poissons durant cette période. L'efficacité p calculée pour toutes les espèces ne diffère pas entre les cinq sites et quelle que soit l'année, entre espèces benthiques ou non-benthiques, ou entre les périodes de régulation ou non. Des différences de p sont seulement observées entre quelques espèces. C_1 diffère significativement entre grandes et petites espèces, à l'exception du gardon, sans être dépendant du nombre de passages. Les résultats indiquent une grande stabilité des deux indices d'échantillonnage dans cette rivière, en dépit du changement de morphologie du cours d'eau après la régulation : des informations qui peuvent être utiles pour de futurs travaux relatifs à l'échantillonnage des cours d'eau.

1 Introduction

Obtaining efficient and accurate fish sampling methods is a problem for researchers, and though no technique produces completely accurate estimates, electric fishing has helped to improve quantitative studies of riverine fish (Platts et al. 1983; Reynolds 1983). As no single sampling technique provides accurate population density estimates (Cormack 1968; Hankin 1984), the combination of sampling methods and well-designed sampling programs is recommended to understand and reduce sampling variability, especially in large rivers (Casselman et al. 1990). Finding one universal method would be advantageous though, because the simultaneous application of more than one sampling method is expensive and time consuming (Knight and Bain 1996; Penczak et al. 1998).

Fishing efficiency depends on the characteristics of a given river in relation to the sampling technique (Mahon 1980; Platts et al. 1983; Reynolds 1983; Zalewski 1983; Hankin 1986; Zalewski and Cowx 1990), while Cuinat (1967) indicated that sampling in mountain streams with high velocities is sometimes not possible. Payne (1986) and Lowe-McConnell (1987) found that in tropical streams, fishing efficiency and sampling accuracy are limited by low conductivity and other factors that vary markedly between seasons. When choosing sampling designs (which differ in their sampling efficiencies), we have to remember that habitat unit size and area also have important effects on fishing efficiency (Hankin 1984; Penczak 1985). The focus of the present study is on factors connected with fishing stability over time, and on effects of the natural state/regulation

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of the stream channel. This is an important approach because of the scarcity of such investigations.

One of the most serious causes of inefficient sampling in streams may be the reliance of studies on a single run for gathering data on fish diversity. However, when one run is consistently applied using a constant unit of effort, its efficiency may be of some value in comparative studies (Lyons and Kanehl 1993; Matthews 1998; Simonson and Lyons 1995; Bravo et al. 1999; Penczak et al. 2000; Maunder 2001). The underlying assumption of this method is that the number of fish obtained by the single run (in our study termed C_1), which is also termed the "relative abundance" or "index abundance" (Lyons and Kaneh 1993; Angermeier and Smogor 1995; Penczak et al. 2000, 2003; Dauwalter and Pert 2003; Pine et al. 2003), remains as a consistent proportion of all fish present in the studied stream, or even across streams. Unfortunately, the usefulness of this parameter is limited, because even small streams show changes between similar stations (Hankin 1984) when they are monitored over a long time frame (Simonson and Lyons 1995).

A long-term sampling experiment was performed in a small, natural, lowland stream in Poland, which is easy to electrofish (Mann 1971; Penczak 1981, 1985). The stream had a bottom dominated by sand, moderate canopy and submerged vegetation, low velocity and banks that were easily accessible. Since 1989, the stream has been regulated by a series of weirs and sluices, a change which provides the opportunity to make a comparison between the 10 year period before this regulation started and the 13 year post-regulation period.

In the present study, p and C_1 might have been affected by the fact that the status of the study stream changed from natural to regulated. Trends in catches that may (or may not) be related to the real variability in population abundance were investigated through the following study questions:

1) How stable is electrofishing efficiency (p) in successive catches and which of the following factors does it depend on?
a) River morphology before and after regulation;
b) Species biology between benthic and non-benthic species;
c) The number of catches: three and six.
2) Is relative abundance (C_1) related to any of the following factors?
a) River morphology before and after regulation;
b) Species biology between benthic and non-benthic species.

2 Materials and methods

2.1 Study area

The study was carried out in the Dobrzynka Stream, a left-hand tributary of the Ner River in the Warta River system (Fig. 1). The length of the stream is about 21 km, its springs lie at 220 m above sea level (a.s.l.), and its mouth is at 165 m a.s.l. (mean slope of 2.2‰).

The stream, which was natural and meandering in the period between 1979 and 1988, has been regulated since the spring of 1989. The position of the sampling sites and location of the weirs are marked in Figure 1c. The first weir is located in the middle of site A (N 51^{o}38·265', E 19^{o}24·167'). During the first year of the study (1979), a 450 m section chosen for sampling was divided into nine 50 m long sites (Penczak 1985), but from 1980 until the end of the study, we combined sites 1+2 into site A, 3+4 into B, 6+7 into D, and 8+9 into E, so each of these new sites was 100 m long. Site 5 was renamed site C and was still only 50 m long. The slope of the river in the sampled reach is 1.83‰.

In the years 1979-88, the natural, meandering stream section, with pools and two riffles (each about ten m long), possessed developed riparian zones of shrubs, emergent plants (mainly reeds) and alders (*Alnus* sp.) growing on the banks of each site; there were some trees or large branches which had fallen into the water, providing shelter for fish. Much of the sampled section was covered by tree- or grass-canopies. Data on stream morphometry, submerged plant cover, and bottom structure were taken from detailed, bathymetric maps (Table 1). Depth changes across the channel were measured (with a 1 cm accuracy) at 5 m stream length intervals. The stream was moderately polluted during this period, and water quality did not change much over the course of this research (Table 2). In 1989, after regulation had been initiated, channel width and depth were uniform, and the stream resembled a ditch. The distance between the fascine fences (running along each bank), made of willow branches and wooden sticks, was 1.7 m, but increased to 2 m close to the weirs constructed in the study area. The banks were stripped of their canopies, and the grassland belts of approximately 40 m width that had adjoined both banks were transformed into bare level land. Plant colonization, of both submerged and emergent vegetation, began anew after 1989 and the stream banks were covered by dense vegetation (grass, reeds) by 1992. Initially, where the running water had not started to destroy the fascines, stream depth was uniform across the streambed, and only dependent on discharge (Table 1).

From 1989 to 2001, only some of the water variables were recorded (Table 2) but, according to the properties that were measured, water quality improved slightly after the stream was regulated. This conclusion is based on the fact that conductivity also decreased, as Allan (1995) reported many examples of linear correlations between the number of dissolved ions and the specific water conductivity, which were related to pollution.

Mean water discharge on the sampling days (in October of 1979-2001) was 0.15 m^3 s^{-1} (0.10 to 0.26 m^3 s^{-1}), and the differences between values obtained in the natural and regulated stream were not significant (P = 0.42). Mean water and air temperatures for October over the 23 years of the study were 13.3 °C (9–14 °C), and 16.4 °C (10–27 °C), respectively, as measured at the end of each sampling period. However, neither of these two parameters was correlated to any significant level with catchability (Spearman r test). In Central Poland, October is a dry or semi-dry month, while floods mostly occur in July, because snow precipitation has only occasionally been high at the end of winter in recent years. One or two floods occur annually, as can be seen by the silt and particles of dry vegetation on riparian vegetation up to 1 m above normal water level.

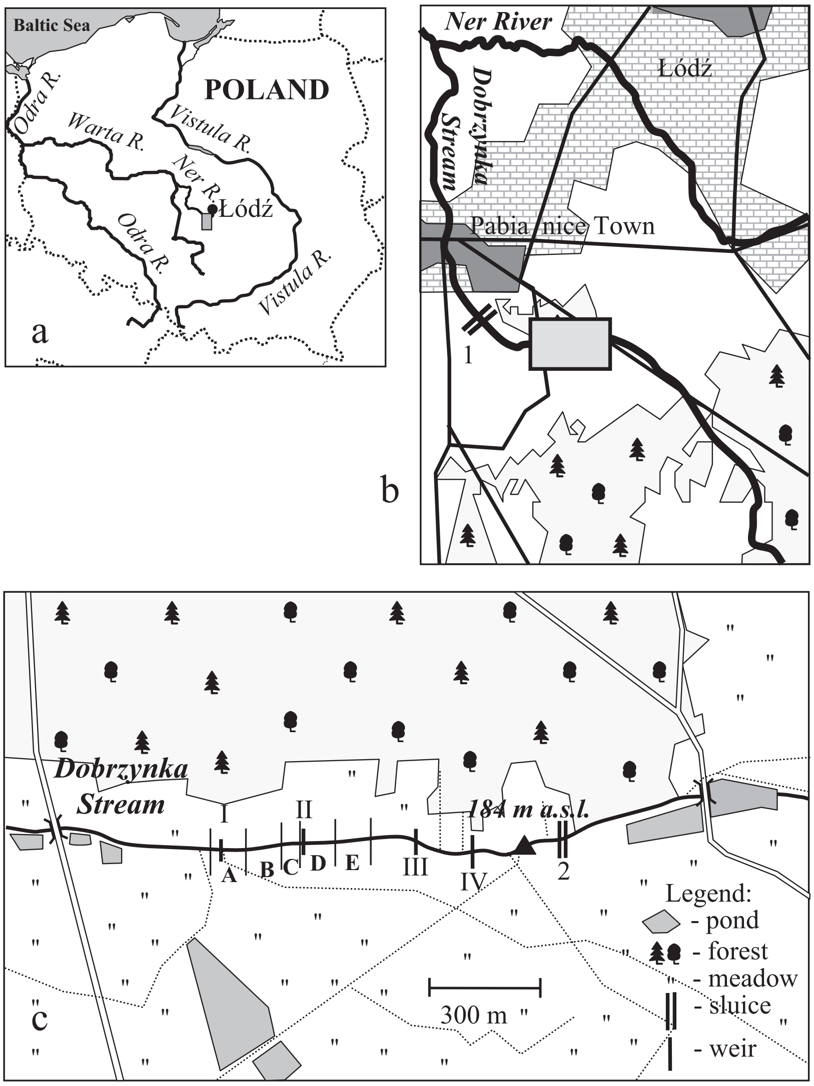

Fig. 1. Description of the study area: (a) map of Poland showing major rivers; (b) pale bricked areas indicate suburban areas, dark bricked areas represent densely urbanized areas, and straight solid lines show roads; (c) A, B, C, D, and E are study sites.

2.2 Sampling

Fish were sampled in the first half of October, usually over two or three days (climatic parameters are usually stable from day to day in Poland during October), and environmental parameters were also collected on the last day of sampling.

A catch per unit effort (CPUE) method was used to evaluate catch at different sites. In the present case, it consisted of six successive electrofishing runs conducted at each site, each lasting 15 min, with a 15 min interval between each run (the period was kept constant because another team was identifying, counting and measuring the collected fish). In the course of the electrofishing runs, two people waded upstream with anode-dipnets, starting from site A, using full-wave rectified current supplied from a 3 kW generator with an output of 220–230 V and 1.5–3.0 A at the dipnets (Penczak 1981). In 1979, each site was isolated before sampling: two stop-nets with a 1.5 mm mesh diameter were used to check how many stunned fish could escape being captured during subsequent runs with anode-dipnets. Because the percentage of escaped fish was lower than 5% during the six runs (9% was the highest single exception), the sites were not enclosed with the stop-nets in subsequent years. Fish were identified to the species level on each sampling occasion, then counted and weighed (to an accuracy of 0.5 g).

2.3 Statistical methods

Zippin's (1956) depletion method of abundance estimation was used to estimate the number, biomass, catchability and other parameters (we recommend paying careful attention to the R parameter in this model when it attains its maximal calculable value due to the high numbers of specimens produced).

Several abundance estimates are used in fisheries studies. The Zippin depletion method was used in the present study because it is the most reliable and frequently used method (Bohlin and Sundström 1977; Bravo et al. 1999;

Table 1. The morphology of sites (A-E) in the Dobrzynka Stream in 1979-1988 and 1989-2001. Notes: ^{a} – number of pools and riffles and maximum depth of pools given in brackets, ^{b} – range is given in brackets, ^{c} – range of bottom area covered by plants (mainly *Elodea canadiensis*) during the first decade of the study, ^{d} – reeds and high grass were so high and overhung the channel to an extent that the water was not visible in many places (bank length percentage), ^{e} – bank length percentage; *Alnus* numbers are given in brackets, shrubs consisted of osiers (*Salix*).

Site	A	B	C	D	E
			1979–1988		
Area (m^2)	245	242	128	264	247
Mean depth (m)^a	0.2	0.25	0.2	0.33	0.35
	(2/1, 0.52)	(2/1, 0.54)	(2/0, 0.75)	(3/0, 1.2)	(1/0, 0.6)
Mean width (m)^b	2.3	2.0	2.5	2.2	2.6
	(1.8–5.7)	(1.7–3.2)	(2.1–3.3)	(1.6–4.2)	(1.6–4.6)
Bottom structure (%)	Sand constituted 90%, gravel and mud about 10%, gravel prevailing in narrow part of the channel, mud in wide part				
Submerged plants (%)^c	15–30	20–40	10–15	5–10	5–10
Emerged plants (%)^d	30–40	25–40	40–60	25–35	10–15
Trees, shrubs (%)^e	10(6)	15(7)	25(22)	30(15)	20(23)
				1989-01	
Area (m^2)	170	170	85	170	170
Mean depth (m)	Usually 0.3 m in most site (ranging to 0.15 or 0.6 m in dry or wet autumn resp.). In two pools just downstream of weirs: 0.71 m (to 0.5 or 1.1 m, in a dry or wet year resp.)				
Bottom structure (%)	Sand constituted 80%, gravel and mud 10% each; in 1993 all sand was covered by a thin layer of mud				
Submerged plants (%)	Yearly mean was 31 (10–42); in 1990, 1992 and 1995 filamentous alga clumps were present among *Elodea canadiensis*				
Emerged plants (%)	Since 1993 a minimum of 50% (up to 80%) of bank length was so overgrown by reeds and high grass that the water surface was invisible from the banks in some channel sections				

Table 2. Physical and chemical data on water quality in the Dobrzynka Stream.

Parameters	Units	Minimum	Mean	Maximum
		1979–1988		
Conductivity	μS 20 °C	390	440	485
pH		7.2	7.5	7.9
Dissolved oxygen	mg O$_2$ L^{-1}	7.4	9.9	11.2
Oxygen saturation	%	61.2	76.7	92.6
BOD$_5$	mg O$_2$ L^{-1}	2.2	3.6	5.8
Phosphate	mg O$_2$ L^{-1}	0.26	0.42	0.67
Ammonium nitrogen	mg O$_2$ L^{-1}	0.36	1.1	1.9
Suspended matter	mg O$_2$ L^{-1}	38	42	60
Velocity	m s^{-1}	0.21	0.35	0.40
		1989-2001		
Conductivity	μS 20 °C	378	391	408
pH		7.4	7.6	7.9
Dissolved oxygen	mg O$_2$ L^{-1}	8.2	8.9	9.7
Oxygen saturation	%	77.4	80.6	88.1
Velocity	m s^{-1}	0.22	0.42	0.55

Penczak et al. 2003). Although the Carle and Strub (1978) method is advocated by some scientists as better when sample abundance is low (Cowx 1983), we know of no study that has actually tested this hypothesis. The MicroFish 3.0 software developed by Van Deventer and Platts (1985, 1989) has gained popularity and been widely applied, for example, by Cowx and van Zyll de Jong (2004). The variant, available as a DOS-based program, is quite comprehensive, yet requires complex DOS file preparation. The method is said to use a simplified version of Zippin's (1956) formulae (Bravo et al. 1999). In the present study, we used our own software that operates directly on Excel files, making it very easy to use. Zippin's (1956) formula was applied here for exact rather than approximate standard error calculation: the latter can only give correct results with samples of more than 200 specimens and our single species samples were frequently lower in number.

Other essential assumptions of the estimate by the Zippin method were:

1) When all specimens, irrespective of their number, were captured in the first run, the species was considered to be "incalculable"; when the number of all captured specimens was <5 in all runs then the species' catch was considered "absolute". In the first case, the logic behind not making the calculation is that all specimens that were in the site have been captured and hence there is no sense in calculating those specimens that were not captured. In the latter case, further estimates were not made due to an inapplicably low number of specimens to be calculated by the method;
2) The variance was not calculated when the catch was either "absolute" or "incalculable"; and
3) Parameter C_1/C_e (efficiency of the first run, in which C_e is defined as the estimated total abundance after six runs per site) was not calculated when the run was "absolute" or "incalculable".

Electrofishing efficiency (p) and C_1/C_e estimates were analyzed using an ANOVA. To avoid confusion, sampling efficiency is referred to as p in the study, as originally proposed by Zippin (1956), while the level of statistical significance is indicated by P. Samples or their groups were first analysed to test their normality, using the Shapiro-Wilk test (the version presently used is that of Royston (1982), which allows the normality of samples of up to 2000 specimens to be estimated). When the sample or a group of samples passed the normality test, the homogeneity of the variance (Levene's test) was tested in all sample pairs. Those samples that did not conform to the test were eliminated from further analysis. Fortunately, this was a small minority of the samples (>1%). After applying the ANOVA test to given sample groups, *post hoc* Tukey or Duncan tests were used to distinguish given sample clusters within the groups. Very small samples (<5) were not considered in analyses. Calculations were carried out using the Statistica 5.5 or 6.0 PL packages.

3 Results

Over the 23 year study period, the following species were recorded: stone loach *Barbatula barbatula* (L.), crucian carp *Carassius auratus* (L.), carp *Cyprinus carpio* L., gibel *Carassius gibelio* (Bloch), spined loach *Cobitis taenia* L., pike *Esox lucius* L., Ukrainian lamprey *Eudontomyzon mariae* (Berg), three-spined stickleback *Gasterosteus aculeatus* L., gudgeon *Gobio gobio* (L.), sunbleak *Leucaspius delineatus* (Heckel), loach *Misgurnus fossilis* (L.), perch *Perca fluviatilis* L., nine-spine stickleback *Pungitius pungitius* (L.), roach *Rutilus rutilus* (L.), bitterling *Rhodeus sericeus* (Pallas), rudd *Scardinius erythrophthalmus* (L.), and tench *Tinca tinca* (L.). Information about the initial study conditions and the population parameters calculated are given in the Appendix.

Neither p nor C_1/C_e differed statistically significantly between any two sites in any period; hence it is not indispensable to publish the data here. To deal with the large initial data set, p of a given species were tested for significant differences between the five sites (A-E), but ANOVA detected no differences either between them or between p of all species pooled or a given site. Differences between p for the six species observed consistently over the entire study period between the sites and for three periods (data for the whole study period, and divided into 1979-1988, 1989-2001) showed that only for roach were these on the verge of significance ($P = 0.04$). Consequently, the catches of given species from all sites in a given year were summed. The product of this totaling was recalculated, applying the Zippin method once more. Information about the initial data and where they are available is presented in the Appendix.

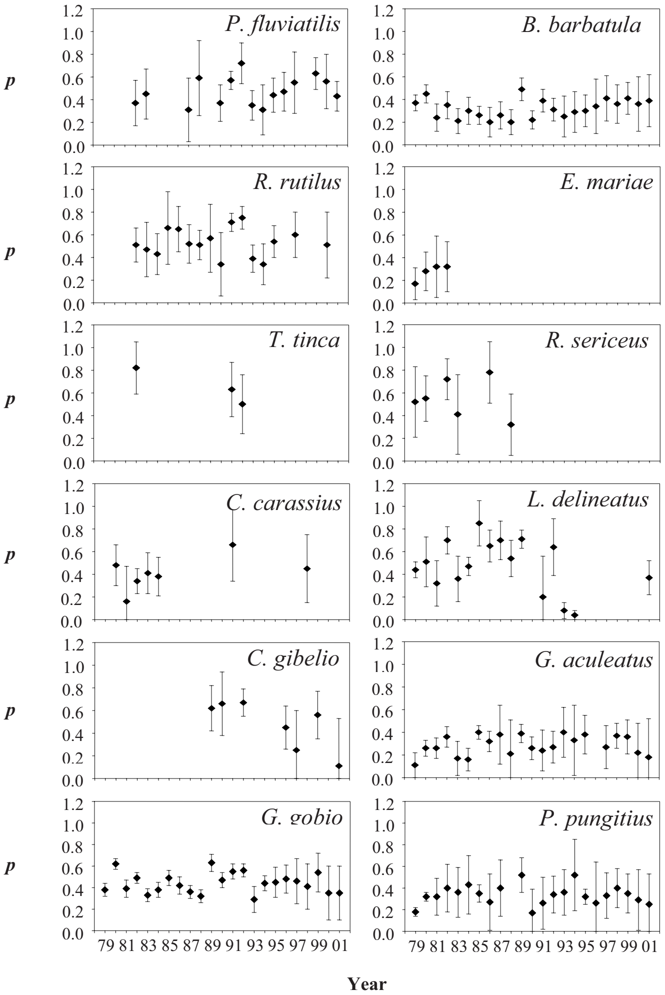

Fig. 2. Mean sampling efficiency (p) calculated for fish species that were sampled in at least three years in the Dobrzynka Stream (species with only "absolute" or "incalculable" catches are excluded); whiskers indicate 95% confidence limits.

3.1 Electrofishing efficiency (p) among periods and species

Mean values and 95% confidence intervals of p are shown in Figure 2. Electrofishing efficiency is presented for species that were abundant throughout the whole study period (thus excluding *S. erythrophthalmus*, *C. carpio*, *M. fossilis*, *C. taenia*) in Figure 3. ANOVA demonstrated a significant species

Table 3. Mean electrofishing efficiency (p) of fish species recorded in the Dobrzynka Stream over the whole study period and Duncan post-hoc tests of their differences (species for which p values could not be calculated at all are excluded from the table). Differences significant at $P < 0.05$ are shown in bold font.

		Species											
Species	Mean p	*R. rutilus*	*E. lucius*	*T. tinca*	*C. carassius*	*C. gibelio*	*G. gobio*	*B. barbatula*	E. mariae	*R. sericeus*	*L. delineatus*	*G. aculeatus*x	*P. pungitius*
P. fluviatilis	0.497	0.731	**0.009**	0.273	0.254	0.556	0.494	**0.009**	**0.002**	0.651	0.963	**0.003**	**0.008**
R. rutilus	0.517		**0.019**	0.168	0.155	0.382	0.333	**0.004**	**0.001**	0.887	0.717	**0.001**	**0.003**
E. lucius	0.664			**0.000**	**0.000**	**0.002**	**0.001**	**0.000**	**0.000**	**0.021**	**0.009**	**0.000**	**0.000**
T. tinca	0.422				0.940	0.562	0.626	0.115	**0.044**	0.138	0.278	0.061	0.113
C. carassius	0.417					0.533	0.600	0.111	**0.048**	0.126	0.262	0.065	0.116
C. gibelio	0.459						0.894	**0.039**	**0.011**	0.330	0.560	**0.017**	**0.037**
G. gobio	0.451							**0.047**	**0.014**	0.284	0.503	**0.021**	**0.045**
N. barbatulus	0.322								0.584	**0.002**	**0.010**	0.693	0.942
E. mariae	0.285									**0.000**	**0.002**	0.850	0.614
R. sericeus	0.526										0.635	**0.001**	**0.002**
L. delineatus	0.494											**0.003**	**0.009**
G. aculeatus	0.296												0.726
P. pungitius	0.317												

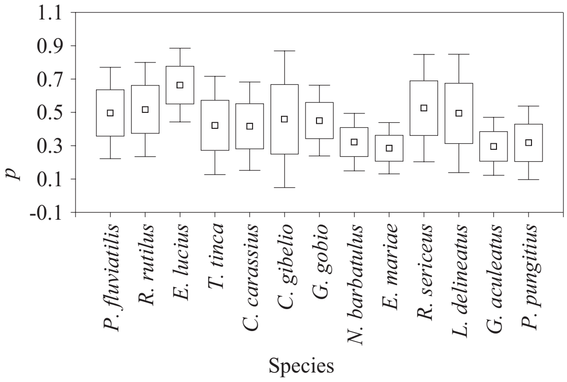

Fig. 3. A comparison of sampling efficiency (p) of species for which it could be calculated in at least three years (plus *Esox lucius*, for which p could be calculated in only one year; which was included because it had the highest p of all the species studied); boxes are standard deviations, whiskers are 1.96 standard deviation (i.e. 95% confidence limits).

effect on p ($P < 0.00001$). Electrofishing efficiency was highest for *E. lucius*, *R. rutilus* and *R. sericeus* (Table 3), lowest for *G. aculeatus* and *E. mariae* (because the spines of *G. aculeatus* get tangled with vegetation that picks up the stunned fish, while *E. mariae* was buried in the sand).

No significant difference was observed in the mean electrofishing efficiency of pooled benthic and non-benthic species over the whole study period (1979-2001; $P = 0.1018$). However, a significant difference was observed in the natural river period (1979-1988; $P = 0.0173$), but not in the regulated stream period (1989-2001; $P = 0.9061$).

No differences were detected in mean p pooled across all species in the natural and regulated stream periods (ANOVA test; $P = 0.7189$). Similarly, no differences were detected between species present for at least several years in both study periods (*P. fluviatilis*, *R. rutilus*, *T. tinca*, *C. carassius*, *G. gobio*, *B. barbatula*, *L. delineatus*, *G. aculeatus*, *P. pungitius*).

ANOVA was also applied to p calculated on the basis of catch data combined over several years. A three-way ANOVA for comparisons between the natural and regulated periods, three and six runs, and benthic and non-benthic species did not show any departure from randomness ($F(1, 314) = 0.345$; $P = 0.557$). A similar comparison of three and six runs with benthic and non-benthic species also displayed no difference in p ($F(1, 314) = 0.599$; $P = 0.44$); a comparison of the natural and regulated periods and benthic and non-benthic species was equally non-significant ($F(1, 314) = 2.562$; $P = 0.110$), as was the comparison of natural and regulated periods and three and six runs ($F(1, 314) = 1.562$; $P = 0.212$).

3.2 Efficiency of the first run (C_1) among periods and species

Variability in the C_1/C_e ratio was analysed only for species that had sufficiently abundant samples both in the natural and regulated river periods (*P. fluviatilis*, *R. rutilus*, *G. gobio*, *B. barbatula*, *G. aculeatus*, *P. pungitius*) (Table 4). The *post-hoc* test on the six abundant species distinguished two groups of three, i.e. (*P. fluviatilis*, *R. rutilus* and *G. gobio*), which were better sampled, and (*B. barbatula*, *G. aculeatus* and *P. pungitius*), which were not as well sampled (Fig. 4a). A similar pattern of fishing efficiency between the species persisted in both the natural and regulated stream periods (Fig. 4b,c), the only difference being that in the regulated river, *P. fluviatilis* and *R. rutilus* (from the first group) were not statistically different from *P. pungitius* of the second group (Table 5).

There was no significant difference between the two periods (natural and regulated) and the data were combined to compare C_1/C_e for all (six) common species together (ANOVA test, $P = 0.1269$, Table 5).

Table 4. Mean C_1/C_e ratios of constant fish species (those that occurred in all or most study years) and Tukey post-hoc tests of their differences in the whole study period (1979-2001), the natural Dobrzynka Stream period (1979-1988), and the regulated Dobrzynka Stream period (1989-2001). Differences significant at $P < 0.05$ are shown in bold font.

		Species				
Species	Mean C_1/C_e	*R. rutilus*	*G. gobio*	*B. barbatula*	*G. aculeatus*	*P. pungitius*
		1979-2001				
P. fluviatilis	0.502	0.823	1.000	**0.000**	**0.000**	**0.001**
R. rutilus	0.556		0.757	**0.000**	**0.000**	**0.000**
G. gobio	0.490			**0.000**	**0.000**	**0.000**
B. barbatula	0.296				1.000	0.951
G. aculeatus	0.306					0.991
P pungitius	0.330					
		1979-1988				
P. fluviatilis	0.476	0.473	0.999	**0.018**	**0.034**	0.050
R. rutilus	0.590		0.259	**0.000**	**0.000**	**0.000**
G. gobio	0.460			**0.007**	**0.015**	**0.025**
B. barbatula	0.263				1.000	0.997
G. aculeatus	0.278					1.000
P pungitius	0.288					
		1989-2001				
P. fluviatilis	0.519	1.000	1.000	**0.016**	**0.024**	0.095
R. rutilus	0.528		1.000	**0.016**	**0.024**	0.091
G. gobio	0.525			**0.005**	**0.011**	**0.040**
B. barbatula	0.322				1.000	0.974
G. aculeatus	0.330					0.992
P. pungitius	0.362					

Table 5. Comparison of mean p and C_1/C_e values of common fish species sampled in the Dobrzynka Stream.

	Species											
	P. fluviatilis		*R. rutilus*		*G. gobio*		*B. barbatula*		*G. aculeatus*		*P. pungitius*	
Period	C_1/C_e	p	C_1/C_e	p	C_1/C_e	p	C_1/C_e	p	C_1/C_e	p	C_1/C_e	p
1979-2001	0.50	0.50	0.56	0.52	0.50	0.45	0.30	0.32	0.31	0.30	0.33	0.32
1979-1988	0.47	0.51	0.59	0.55	0.46	0.42	0.26	0.29	0.28	0.27	0.29	0.30
1989-2001	0.52	0.49	0.53	0.49	0.53	0.48	0.32	0.35	0.33	0.32	0.36	0.33
	Variance											
1979-2001	0.021	0.020	0.032	0.021	0.015	0.012	0.010	0.008	0.011	0.008	0.017	0.013
1979-1988	0.027	0.030	0.022	0.012	0.013	0.009	0.007	0.006	0.012	0.008	0.010	0.007
1989-2001	0.019	0.015	0.042	0.028	0.016	0.014	0.012	0.008	0.009	0.007	0.021	0.017

4 Discussion

Of the two fishing efficiency parameters investigated in the study, p and C_1, the first has never been defined unambiguously in literature (Zalewski and Cowx 1990): p is the probability that individuals will be captured during at least two runs, determined from the Zippin (1956, 1958) method, and its value changes with the number of sampling runs. When the number of runs is only two, p is always equal to C_1. However, with an increase in the number of runs, a difference usually appears and continues to increase with the number of catches (Riley and Fausch 1992). This was also the case in the Dobrzynka, however the differences between C_1 and p were never statistically significant for any of the common species (Table 5, ANOVA test). The only difference in the Dobrzynka was in the variance, which was larger in the case of smaller catches, yet this was, to a certain degree, species-dependent (Mann 1971). The problem of decreasing catchability was also considered by Bohlin and Cowx (1992), who attributed it to stress caused by earlier runs or lower catchability of certain individuals within given species.

The mean differences between the C_1/C_e ratio and p calculated from yearly means, were different among the dominant species. In the case of *P. fluviatilis*, *R. rutilus*, *G. gobio* and *G. aculeatus*, the C_1/C_e was higher than p, but in the case of *B. barbatula* and *P. pungitius*, p was higher than C_1/C_e. However, in neither of these groups were the differences significant ($P < 0.5$).

To compare results with those obtained by other researchers using the Zippin model, p for temperate (Riley and Fausch 1992; Penczak et al. 1994) and tropical zones (Penczak and Lasso 1991; Agostinho and Penczak 1995) was compared, but was not significantly different and there was a clear overlapping among p for some species. This suggests that p, calculated for species in a small stream, is useful for assessing the efficiency of sampling in other ecosystems. On the other hand, p tends to decrease with an increase in the number of runs, and is independent of habitat complexity (Riley and Fausch 1992). In the Dobrzynka, the decrease in p with successive runs was

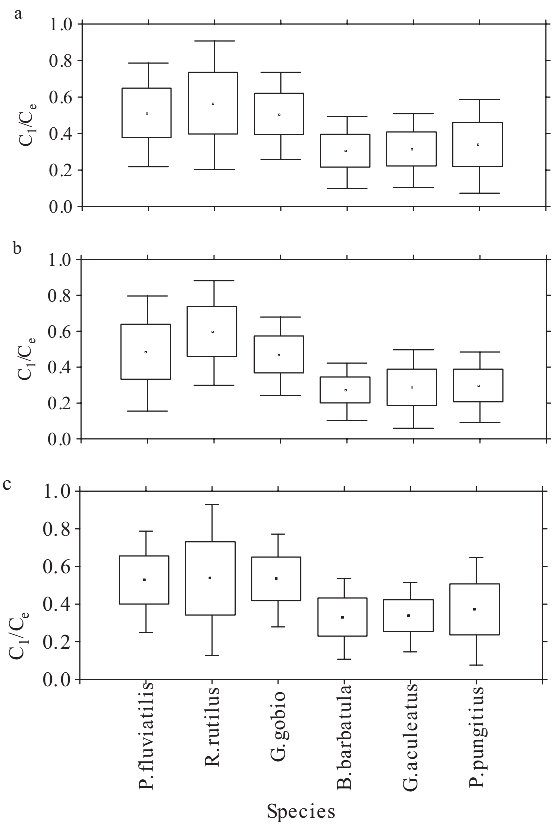

Fig. 4. C_1/C_e ratio, number of fish obtained during the first runs (C_1), and six runs per site (C_e). Differences between species that were consistently observed in the Dobrzynka Stream during: (a) the whole study period; (b) the period when the Dobrzynka Stream was unregulated; and (c) the period when the Dobrzynka Stream was regulated.

not significant. According to Riley and Fausch (1992), maintaining constant effort on each run is essential for maintaining stability in p.

Relative abundance, C_1, seems to be an adequate measure of river fish diversity (Libosvarsky 1966; Zalewski 1983, 1985; Heimbuch et al. 1997; Bravo et al. 1999; Meador et al. 2003). In an earlier study conducted in a stream, Chmielewski et al. (1973) found that the first run efficiency was low for some species, but this could have resulted from the imperfect equipment available at that time.

Because the knowledge of riverine ichthyofauna in some parts of the world is still in its infancy, qualitative pilot studies based on C_1 are still recommended (Knight and Bain 1996; Penczak et al. 1998). The present study indicates that C_1 calculated as a mean for the Dobrzynka data for the whole period (total pool) was high (mean 0.432, standard deviation 0.187, range 0.11–0.84) and mainly concerned small bodied species that remained within the range 20–40%. In the Dobrzynka, this value was not impacted by site differences over the 23 years or by the fact that the river was first natural and then regulated.

Over the course of a monitoring study, p and C_1 can fluctuate in successive years because these variables can be affected by strongly differentiated species biology. This effect is shaped by environmental parameters, as has been shown for non-salmonid fish in European rivers (Wootton 1990; Mann 1996).

Appendix

The study dataset, recalculated using the Zippin method, consists of 115 A4 pages, each of which contains abundance and biomass data for each species from six sample runs obtained in each site in each year. The tables present the following parameters: p, C_1/C_e – ratio of C_1 to C_e, χ^2 – Chi-square test of the difference between the hypothetical values of given catches (not presented here) and the actual values, i.e. C_1 through C_6; Sign. of χ^2 – significance of the test; C_e 100 m^{-2} – abundance of specimens recalculated per 100 m^2; +95% confidence limit, C_e 100 m^{-2} – upper 95% confidence limit of abundance per 100 m^2; –95% confidence limit, C_e 100 m^{-2} – lower 95% confidence limit of abundance per 100 m^2. All of this material is available on request, as it cannot be published here due to its length.

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References

Agostinho A.A., Penczak T., 1995, Populations and production of fish in two small tributaries of the Paraná River, Paraná, Brazil. Hydrobiologia 312, 153–166.

Allan J.D., 1995, Stream Ecology. Structure and Function of Running Waters. Chapman & Hall, London.

Angermeier P.L., Smogor R.A., 1995, Estimating the number of species and relative abundance in stream-fish communities: effects of sampling effort and discontinuous spatial distributions. Can. J. Fish. Aquat. Sci. 52, 936–949.

Bohlin T., Cowx I.G., 1992, Implications of unequal probability of capture by electric fishing on the estimation of population size. In: Cowx I.G. (Ed.), Developments in Electric Fishing. Blackwell Scientific Publications, Oxford, pp. 145–155.

Bohlin T., Sundström B., 1977, Influence of unequal catchability on population estimates using the Lincoln index and the removal method applied to electro-fishing. Oikos 28, 123–129.

Bravo R., Soriguer M.C., Villar N., Hermando J.A., 1999, A simple method to estimate the significance level on the catch probability in the catch removal method in river fish populations. Fish. Res. 44, 179–182.

Carle F.L., Strub M.R., 1978, A new method for estimating population size from removal data. Biometrics 34, 621–630.

Casselman J.M., Penczak T., Carl L., Mann R.H.K., Holcik J., Woitowich W.A., 1990, An evaluation of fish sampling methodologies for large river systems. Pol. Arch. Hydrobiol. 37, 521–551.

Chmielewski A., Cuinat R., Dembinski W., Lamarque P., 1973, Fatigue and mortality effects in electrical fishing. Pol. Arch. Hydrobiol. 20, 241–348.

Cormack R.M., 1968, The statistics of capture-recapture methods. Oceanogr. Mar. Biol. 6, 455–506.

Cowx I.G., 1983, Review of the methods for estimating fish population size from survey removal data. Fish. Manage. 14, 67–82.

Cowx I.G., van Zyll de Jong M.C., 2004, Rehabilitation of freshwater fisheries: tales of the unexpected? Fish. Manage. Ecol. 11, 243–249.

Cuinat R., 1967, Contribution to the study of physical parameters in electric fishing in rivers with direct current. In: Vibert R. (Ed.) Fishing with electricity – its applications to biology and management. FAO, Fishing News (Books) Ltd., London, pp. 131–171.

Dauwalter D.C., Pert E.J., 2003, Electrofishing effort and fish species richness and relative abundance in Ozark Highland Stream of Arkansas. N. Am. J. Fish. Manage. 23, 1152–1166.

Hankin D.G., 1984, Multistage sampling designs in fisheries research: applications in small streams. Can. J. Fish. Aquat. Sci. 41, 1575–1591.

Hankin D.G., 1986, Sampling designs for estimating the total number of fish in small streams. Res. Pap. PNW-360. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Heimbuch D.G., Wilson H.T., Weisberg S.B., Volstand J.H., 1997, Estimating fish abundance in stream surveys by using double-pass removal sampling. T. Am. Fish. Soc. 126, 795–803.

Knight J.G., Bain M.B., 1996, Sampling fish assemblage in forest floodplain wetlands. Ecol. Freshw. Fish. 5, 76–85.

Libosvarsky J., 1966, Successive removals with electrical fishing gear: a suitable method for making populations estimates in small streams. Verh. Int. Verein. Limnol. 16, 1212–1216.

Lowe-McConnell R.H., 1987, Ecological studies in tropical fish communities. Cambridge University Press, Cambridge.

Lyons J., Kanehl P., 1993, Comparison of four electrofishing procedures for assessing the abundance of smallmouth bass in Wisconsin streams, Technical Report NC-159. General U.S. Forest Service, North Central Forest Experimental Station, St. Paul, Minnesota.

Mahon R., 1980, Accuracy of catch-effort methods for estimating fish density and biomass in streams. Environ. Biol. Fish. 5, 343–363.

Mann R.H.K., 1971, The populations, growth and production of fish in four small streams in Southern England. J. Anim. Ecol. 40, 155–190.

Mann R.H.K., 1996, Environmental requirements of European non-salmonid fish in rivers. Hydrobiologia 323, 223–235.

Matthews W.J., 1998, Patterns in freshwater fish ecology. Chapman & Hall, New York.

Maunder M.N., 2001, A general framework for integrating the standardization of catch per unit of effort into stock assessment models. Can. J. Fish. Aquat. Sci. 58, 795–803.

Meador M.R., McIntyre J.P., Pollock K.H., 2003, Assessing the efficacy of single-pass backpack electrofishing to characterize fish community structure. Trans. Am. Fish. Soc. 132, 39–46.

Payne A.L., 1986, The ecology of tropical lakes and rivers. J. Wiley & Sons, Chichester.

Penczak T., 1981, Ecological fish production in two small lowland rivers in Poland. Oecologia 48, 107–111.

Penczak T., 1985, Influence of site area on the estimation of the density of fish populations in a small river. Aquac. Fish. Manage. 1, 273–285.

Penczak T., Lasso C., 1991, Problems of estimating populations parameters and production of fish in a tropical rain forest stream, North Venezuela. Hydrobiologia 215, 121–133.

Penczak T., O'Hara K., 1998, Accuracy of fish population estimates in a navigation canal with heavy traffic. Fish. Res. 35, 191–198.

Penczak T., Galicka W., Głowacki Ł., Koszaliński H., 1994, Fish stocks in the Warta River: continued post-impoundment study (1990-1992). Pol. Arch. Hydrobiol. 41, 347–363.

Penczak T., Gomes L.C., Bini L.M., Agostinho A.A., 1998, The importance of qualitative inventory sampling using electric fishing and nets in a large, tropical river (Brazil). Hydrobiologia 389, 89–100.

Penczak T., Kruk A., Koszaliński H., Kostrzewa J., Marszał L., Galicka W., Głowacki Ł., 2000, Fishes of three oxbow lakes and their parent Pilica River: 25 years later. Pol. Arch. Hydrobiol. 47, 115–130.

Penczak T., Głowacki Ł., Kostrzewa J., Kruk A., Koszaliński H., Galicka W., Marszał L., Zięba G., 2003, Influence of climate-related temporal changes on fish assemblages in oxbow lakes and in their parent Pilica River (continuation). Ecohydrol. Hydrobiol. 3, 71–85.

Pine W.E., Pollock K.H., Hightower J.E., Kwak T.J., Rice J.A., 2003, A review of tagging methods for estimating fish populations size and components of mortality. Fisheries 28, 10–23.

Platts W.S., Megahan W.F., Minshall G.W., 1983, Methods for evaluating stream, riparian, and biotic conditions. GTR-INT-138, series number PB83-225300AO5 – NTIS Info. USDA, Forest Service, Intermountain Forest and Range Experimental Station, Ogden, UT.

Reynolds J.B., 1983, Electrofishing. In: Nielsen L.A., Johnson D.L., (Eds.) Fisheries techniques. American Fisheries Society, Bethesda, Maryland, pp. 147–163.

Riley S.C., Faush K.D., 1992, Underestimation of trout population size by maximum-likelihood removal estimates in small streams. N. Am. J. Fish. Manage. 12, 768–776.

Royston J.P., 1982, An extension of Shapiro and Wilk's W test for normality to large samples. Appl. Stat. 31, 115–124.

Simonson T.D., Lyons J., 1995, Comparison of catch per effort and removal procedures for sampling stream fish assemblages. N. Am. J. Fish. Manage. 15, 419–427.

Van Deventer J.S., Platts W.S., 1985, A computer software system for entering, managing and analyzing fish capture data from streams. Res. Note–INT-352, Ser. Number PB86-125192AO2. USDA, Forest Service, Intermountain Forest and Range Experimental Station, Ogden, UT.

Van Deventer J.S., Platts W.S., 1989, Microcomputer software system User Guide. GTR-INT-254, Series Number PB89-151690AO3. USDA, Forest Service, Intermountain Forest and Range Experimental Station, Ogden, UT.

Wootton R.J., 1990, The ecology of teleost fishes. Chapman and Hall, London.

Zalewski M., 1983, The influence of fish community structure on the efficiency of electrofishing. Fish. Manage. 14, 177–186.

Zalewski M., 1985, The estimate of fish density and biomass in rivers on the basis of relationships between specimen size and efficiency of electrofishing. Fish. Res. 3, 147–155.

Zalewski M., Cowx I.G., 1990, Factors affecting the efficiency of electric fishing. In: Cowx I.G., Lamarque P. (Eds.) Fishing with electricity. Applications in freshwater fisheries management. Fishing News Books, Oxford, pp. 89–111.

Zippin C., 1956, An evaluation of the removal method of estimating animal populations. Biometrics 12, 163–189.

Zippin C., 1958, The removal method of population estimation. J. Wildlife Manage. 22, 82–90.