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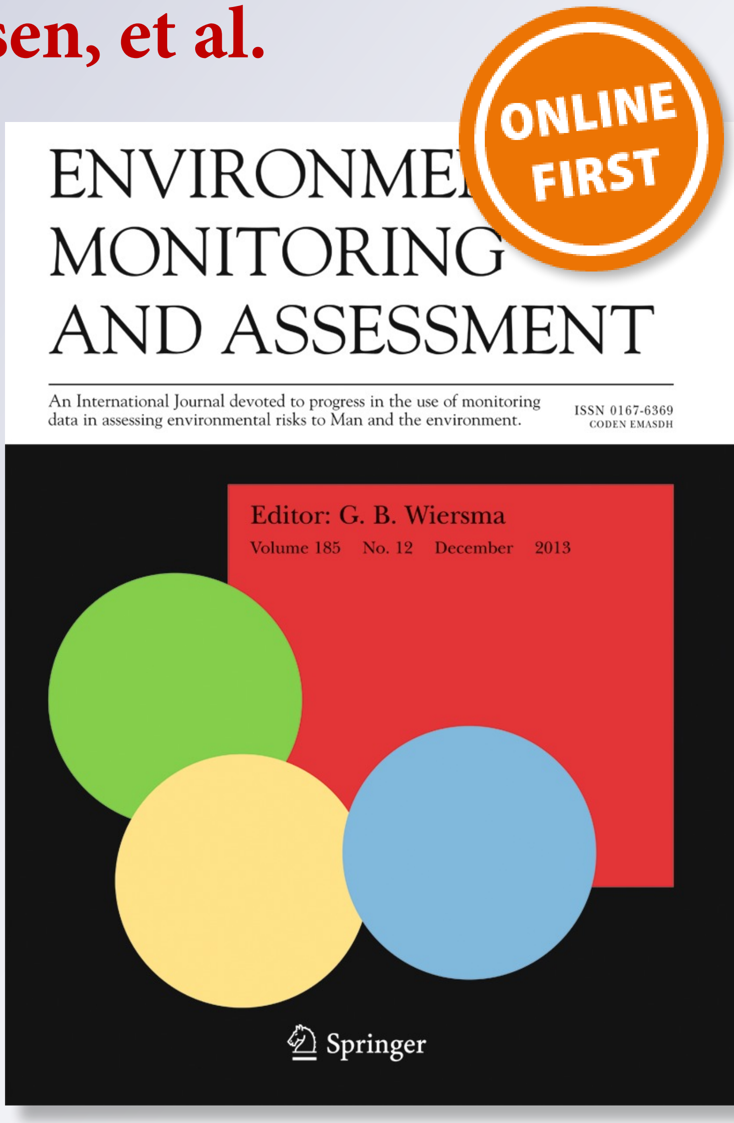

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Abstract Electrofishing is considered a reliable tool to assess the assemblages and biodiversity of fish in wadeable streams. The most widely used electrofishing techniques (point [P], single-pass [S-P], and multiple-pass [M-P]) vary as to the effort needed for sample collection, and this may potentially influence the degree of accuracy. Moreover, little is known about the comparability of the methods and their specific performance in streams with different fish assemblages. The aim of this investigation was to validate (using M-P sampling as reference) the use of P and S-P electrofishing techniques to accurately assess the richness, density and size distribution of fishes in small streams at both regional and global scale independently of fish assemblages and geographical region. We sampled 50-m-long reaches in a total of 33 lowland stream reaches that were located in different climatic and biogeographical regions (Uruguay and Denmark) and hosted different fish assemblages. Subtropical fish communities exhibited higher richness (Uy: 12–32, Dk: 1–9) and densities (Uy: 1.3–5.2, DK: 0.1–4.9 in. m^{-2}) than temperate streams. We applied both "global models" using the entire database (33 sites) and "local models" including the same number of sites but using the climatic region as a model variable. Regression analyses revealed that the P, S-P and M-P methods all provided an adequate picture of the species composition and size distribution, and transfer equations for comparison between methods are thus not required. Conversely, richness was better predicted by S-P and by P techniques for regional and global models, respectively. Transfer equations obtained for abundance revealed that the P and S-P models can accurately transform catch data

F. Teixeira-de Mello · M. Meerhoff · I. González-Bergonzoni · C. Iglesias · N. Mazzeo
Departamento de Ecología & Evolución, CURE-Facultad de Ciencias, Universidad de la República, Tacuarembó s/n, Maldonado CP 20000, Uruguay

F. Teixeira-de Mello · M. Meerhoff · I. González-Bergonzoni · C. Iglesias
Asociación Civil Investigación y Desarrollo I+D, Iguá 4225, CP 11400 Montevideo, Uruguay

E. A. Kristensen · M. Meerhoff · I. González-Bergonzoni · A. Baattrup-Pedersen · P. B. Kristensen · E. Jeppesen
Department of Bioscience, Aarhus University, Vejlsøvej 25, 8600 Silkeborg, Denmark

I. González-Bergonzoni · E. Jeppesen
Sino-Danish Centre for Education and Research (SDC), Beijing, China

E. Jeppesen
Greenland Climate Research Centre (GCRC), Greenland Institute of Natural Resources, Kivioq 2, P.O. Box 570 3900, Nuuk, Greenland

F. Teixeira-de Mello (✉)
Ecología y Rehabilitación de Sistemas Acuáticos, CURE-Facultad de Ciencias, Universidad de la República, Tacuarembó s/n, Maldonado CP 20000, Uruguay
e-mail: frantei@fcien.edu.uy

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into M-P estimations. The transfer equations provided here may have great relevance as they allow relatively reliable comparisons to be made between data obtained by different techniques. We also show that less intensive sampling techniques may be equally useful for monitoring purposes as those requiring more intensive efforts (and costs). We encourage validation of our developed transfer equations on data from other regions of the world.

Keywords Electrofishing methods · Active gear · Sampling effort · Fish assemblages · Fish monitoring · Temperate streams · Subtropical streams

Introduction

Fish communities are widely used for assessing the environmental quality of streams (e.g., Karr 1981; Peterson et al. 2011). Various attributes are considered including species richness, presence–absence of indicator species, trophic guilds, and abundance and occurrence of diseases or hybrids (Steedman 1988; Fausch et al. 1990). Obtaining quality and trustable data is one of the major concerns in such assessments, and for this purpose reliable and comparable fish sampling methods are needed to gather both quantitative and semi-quantitative data. Fish sampling typically includes two different approaches, namely active (those relying on the activity of the sampling gear) and passive (those relying on the activity of the fish) methods. Both strategies hold their advantages and disadvantages; for example, the efficiency of passive methods depends highly on fish activity (Hamley 1975; Rudstam et al. 1984), which, in turn, is affected by both intrinsic (e.g., circadian cycles; Reebs 2002) and extrinsic variables (e.g., light and temperature; Stoner 2004; Linlokken and Haugen 2006; Gelós et al. 2010). Additionally, most of the passive fish sampling methods are strongly selective as to fish traits and habitat use.

Active methods are those most commonly employed to survey stream fish communities and especially electrofishing has been widely applied during the past 80 years (Burr 1931; Haskell 1940). Electrofishing is one of the most reliable methods to survey fish assemblages in wadeable streams (Granado 1996; Gardner 1997) and is considered the least biased, least destructive and most cost-effective approach (Persat and Copp 1990). Some of the most widely used techniques include point (P), single (S-P) and multiple-pass (M-P) electrofishing that varies regarding the effort needed to gather the samples and as to the fish processing time afterwards (i.e., the longer the sampling time, the higher the catch) (Gardner 1997; Janáč and Jurajda 2007; Sály et al. 2009).

Point electrofishing implies sampling of numerous small units by applying electricity in a specific area (i.e., point) for a chosen time period and repetition of the procedure some distance apart in a new area (one or two meters between points). S-P and M-P techniques both aim to sample as many individuals as possible by moving through a specific stream reach and applying electricity in the entire area (Bohlin et al. 1989). As indicated by the method name, S-P electrofishing involves only one sampling at each stream reach, while M-P electrofishing implies repetition of passes, with an a priori *criterion* for when to stop, often involving a doubling or tripling of the fishing effort (and the duration) compared to the S-P method (Bohlin et al. 1989). All three methods allow some deviation from basic procedures and may be performed in closed stream segments (by blocking both ends with nets) or in open segments (without block nets) (Peterson et al. 2005). The P and S-P sampling methods produce catch-per-unit-effort (CPUE) data and are typically fast and economical; M-P is the only method permitting estimation of natural abundance and richness, but is typically more time consuming. Given the financial and human resources needed to sample stream fishes, improving sampling efficiency without compromising the data quality is of key importance (Smith and Jones 2005).

Although the most accurate estimations are expectedly provided by the M-P method, logistic and ethical considerations (considering the number of fish individuals caught) may render application of the other methods more appropriate. For this purpose, transfer equations between methods with low and high sampling effort may be necessary.

Albeit all the above methods have been widely used in surveys, little is known about their comparability and specific performance with different fish assemblages. Fish body size and species-specific differences in sensitivity, as well as the physical characteristics of the streams, may cause undesirable bias due to changes in catch efficiency (Rodgers et al. 1992; Bayley and Dowling 1993; Anderson 1995; Angermeier and Smogor 1995; Baldwin and Aprahamian 2012). Even in similar streams, the various community attributes of fish communities, such as species richness and composition, density and size distribution, often differ among biogeographical and climate zones (e.g., Teixeira-de Mello et al. 2012). The efficiency of sampling methods and the required sampling effort to obtain reliable results might therefore differ as well.

For streams with contrasting fish assemblages, we compared the accuracy of the data obtained by P and S-P electrofishing with the data estimated by M-P electrofishing within each system. The results obtained from the estimation by M-P samplings were used as references, our aim being to build relationships to reliably transform the richness and abundance data obtained with P and S-P sampling to M-P estimated values. A further objective was to compare fish size and assemblage structure determined by the three different methods. Several representative streams were sampled from two different climatic and biogeographical regions, temperate–palearctical in Denmark and subtropical–neotropical in Uruguay. This allowed evaluation of the performance of different electrofishing strategies in streams showing a distinctive structure of fish assemblages (Teixeira-de Mello et al. 2012) and of the possible application of transfer equations for extrapolation of the different fish community attributes.

Materials and methods

Design and sampling methodology

Study area

We sampled 50 m long reaches in a total of 33 lowland streams in two regions, temperate Denmark and subtropical Uruguay (hereafter Dk and Uy), between February 2009 and June 2011. The fish communities in the streams selected in both countries are representative for the community attributes presented in the review of Teixeira-de Mello et al. (2012) of a large number of streams from the same biogeographical and climate regions. Fish assemblages from Uruguay are characterized by considerably higher richness and density and smaller individuals compared to the assemblages found in similar sized streams with identical phosphorous levels in Denmark (Teixeira-de Mello et al. 2012).

Physical characteristics of the streams

To obtain a detailed physical characterization of the stream reaches and to compare the environmental attributes among regions, we determined water depth, type of substrate, current velocity and macrophyte coverage in 25×25 cm plots along cross-sectional transects located every 10 m along the 50 m reach. Water depths were measured to the nearest centimeter at a fixed point in each of the quadrants and mean depth was then calculated from these measurements. The three dominant substratum types in each quadrant were identified and classified as: stone (>60 mm), gravel (3–60 mm), sand (<3 mm), clay/silt, mud and debris (remains of plant material). Subsequently, we calculated the relative frequency of the various substratum types along the reach. Also macrophyte cover was recorded in each quadrant (Friberg et al. 2005) and average coverage was calculated for each stream reach.

Fish assemblages

All stream reaches were sampled in an upstream direction by a three-person team: the team leader (the same person at all sampling events to ensure standardization) applying the electric pulse and capturing fish with a hand net, the first assistant walking together with the team leader and assisting in the capture with another hand net and the second assistant walking a few steps behind, carrying a bucket of water and assisting in handling the catch. To better spot the fish under the water, both the team leader and the first assistant wore polarized sunglasses.

The 33 (Dk: 20 and Uy: 13) 50-m-long stream reaches were sampled without block nets using the three different electrofishing methods (P, S-P and M-P) during 2 consecutive days. On the first day, P electrofishing was performed by applying one electric pulse per meter, i.e., in total 50 electric pulses along each reach. All the fish caught were pooled in one sample, handled carefully (using battery supplied aerators and measuring fishes as rapidly as possible) and subsequently reintroduced to the middle of the reach. On day 2, M-P electrofishing was carried out, and the data from the first and the consecutive passes were stored separately (simultaneously generating the database on the S-P and M-P results). All individuals were identified to species level and counted in situ. In a subset of the studied systems (Dk: 8 and Uy: 8) fish lengths were measured to the nearest cm (standard length, SL), yielding sufficiently clear patterns.

Equipment bias

Since two different types of standard electrofishing equipment were used (230 V generator, 6A and anode diameter 25 cm in Dk; 12 V battery, 6A and anode diameter 25 cm in Uy), we checked for any potential bias in size selectivity following Junge and Libosvárský (1965). As with Teixeira-de Mello et al. (2012), we found that the two equipment types had a similar high catch probability (estimated as $p=(C_1-C_2)/C_1$ (where C_1 is the total number caught in the first pass and C_2 is the total number caught in the second pass); $p=0.60\pm0.02$ [SE] and $p=0.56\ \pm0.03$ [SE] for Dk and Uy, respectively) and accordingly assumed a low bias in total population size estimations due to size selectivity when $p>0.5$ (Junge and Libosvárský 1965).

Statistical approach

Environmental analyses

After standardizing the environmental variables, we used principal components analysis (PCA) to identify (dis)similarities between the environmental conditions of streams from the two climatic regions. Statistical significance of (dis)similarities between the two sets of streams considering environmental conditions was tested using one-way analysis of similarity (one-way ANOSIM, 9,999 permutations; distance measure: complement $1-r$ of Pearson's r correlation). Besides, to evaluate the potential effects of each environmental variable on capture probability (estimated as $p=(C_1-C_2)/C_1$ between S-P and M-P, see above), we performed a multiple regression. In the case of species richness, the relationships between the area and volume sampled and between the number of species caught only when applying the M-P technique (rare species lost in the first pass or in the point sampling) were also evaluated.

Fish richness and abundance

Species richness and abundances obtained by P and S-P sampling will often be lower than those estimated by the M-P method. We therefore applied a regression-based approach to determine the relationship and to obtain transfer equations for species richness and abundance among each of the P and S-P sampling events with those obtained by the M-P method. Total richness and abundance were estimated for the M-P catches using the removal model (Seber and Le Creen 1967), and relative species richness (considering M-P estimated richness as total richness) was estimated for the P and S-P catches. The abundance and richness data were transformed by $\log_{10}(x)$ prior to analysis in order to obtain a normal distribution.

To search for relationships between richness and densities identified from the P and S-P samplings with those estimated from the M-P sampling, we performed separate linear regression analyses for each climatic region. We then evaluated which regression equations (i.e., transfer equations) best predicted the richness and densities obtained by the estimates from the M-P and from the P and S-P sampling procedures (Strange et al. 1989; Jones and Stockwell 1995). We applied both "global models" using the entire database (33 sites) and "local models" including the same number of sites but using the climatic region as a model variable. To identify which models were the best for predicting the richness and abundance results obtained with the M-P sampling method, we used the Akaike information criterion (AIC, Motulsky and Christopoulos 2003), defined as:

$$\mathrm{AIC} = -2 * \log \mathrm{Lik} + 2N,$$

where N represents the number of parameters estimated by the model and log Lik corresponds to the logarithm of maximum likelihood. The best model is the one with the lowest AIC value. In a few words, ΔAIC values are calculated for each model to show the amount of support (Δ) for a given model (i.e., acceptable strong support Δ <3; Burnham and Anderson 2002). In the case of species richness and abundance (after $\log_{10}(x)$ transformation, continuous variables), normal distribution and identity link functions were used. In cases where the "global model" had stronger support than the "local model", the possible differences between both model slopes were tested with an analysis of covariance (ANCOVA) using region as categorical factor (Fig. 1).

Species composition

We compared the specific composition of species caught by the three methods (P, S-P and M-P) using the matrix of relative abundance and presence–absence data. We analyzed the correlations (Pearson correlation coefficient) between these matrices employing the Mantel test (Mantel 1967). The similarity matrix of

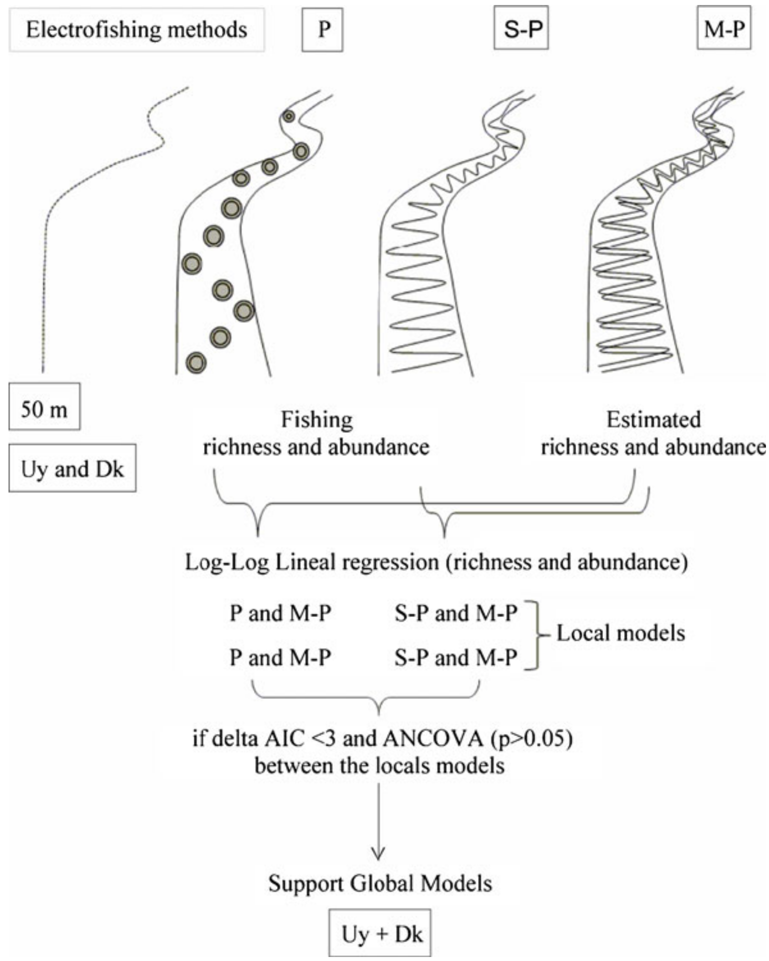

Fig. 1 Map of the sampling and statistical analysis strategy. *P* point electrofishing, *S-P* single pass, *M-P* multiple-pass, *Uy* Uruguay, *Dk* Denmark, *AIC* Akaike information criterion

relative abundance was calculated with the Bray–Curtis similarity index and for the presence–absence data we used the Jaccard similarity index. In all cases, we performed 10,000 random permutations using PAST software (Hammer et al. 2001). Moreover, we compared relative species abundance between the three electrofishing methods for all species present in at least three streams using Kruskall–Wallis analysis.

Body size

Fish size affects the probability of capture during electrofishing; larger individuals are more susceptible to being captured and the capture of large individuals may therefore be higher in the first pass than in subsequent passes (Mahon 1980). Consequently, we therefore evaluated whether the different electrofishing methods generated different size distributions of the fish assemblages. We measured fish standard length in a subset of the sampled streams (8 streams in each climatic region) within a discrete range of 1 cm (i.e., fish measuring between 1 and 1.9 cm were included in Size Class 1). Differences in the size of individuals captured (size selectivity) between the three methods were evaluated graphically, and the mean relative abundance (%) per size class collected with each method was compared statistically. For each size class, we considered each stream reach as a replica and performed a Kruskall–Wallis analysis for all size classes occurring in at least three streams.

Results

Environmental conditions

The environmental variables measured in the streams exhibited wide variation and there was a high degree of overlap between the two countries (Table 1). Width and

Table 1 Environmental characteristics (mean and range) of the streams from Denmark (Dk, n=20) and Uruguay (Uy, n=13)

Environmental characteristics	Dk streams	Uy streams
Width (m)	4.6 (2.8–8.7)	3.9 (1.2–8.2)
Depth (cm)	0.3 (0.1–0.6)	0.3 (0.1–0.5)
Mud (% coverage)	30.6 (0.4–70.3)	35.6 (0–100)
Sand (% coverage)	42.0 (8.2–73.5)	29.0 (0–83.0)
Gravel (% coverage)	30.1 (0–74.0)	15.3 (0–48.6)
Rock (% coverage)	4.5 (0–21.4)	20.2 (0–88.9)
Macrophyte (% coverage)	18.6 (0–57.3)	32.3 (0–84.0)
Water velocity (m s^{-1})	0.2 (0–0.2)	0.2 (0.1–0.6)

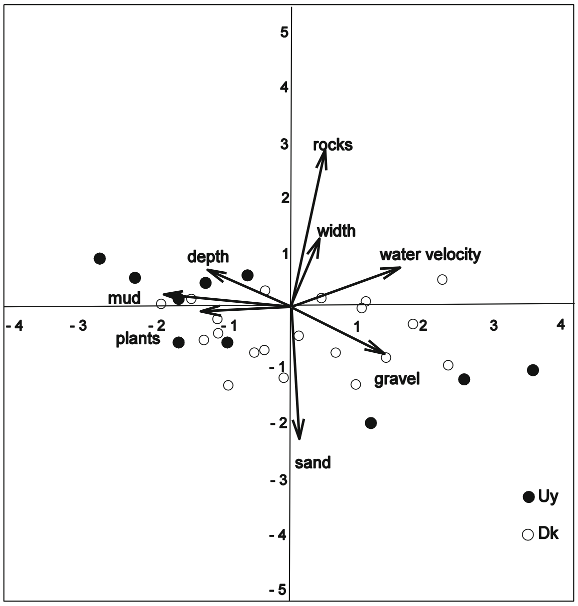

Fig. 2 Spatial ordinations of the streams studied and the main environmental gradients detected by the PCA analysis using sediment type, water velocity, macrophyte coverage, depth and width as environmental variables. *Black circles* represent subtropical streams and *white circles* temperate streams. PCA axes 1 and 2 explained 32.3 % and 19.9 % of total variance, respectively. Total n=33

depth varied widely among the sampling segments in both regions and so did area (Uy 62.0–411.7 m^2 and Dk 85.3–433.5 m^2) and volume (Uy 14.8–133.9 m^3 and Dk 19.7–137.5 m^3). The first PCA axis explained 32.3 % (positive correlation with water velocity r= 0.75 and gravel r=0.69, negative correlation with mud r=−0.91 and plant coverage r=−0.72), while the second PCA axis explained 19.9 % (positive correlation with rocks r=0.86 and negative correlation with sand r=−0.72) of the total variance. Besides, the indirect ordination did not show a regional grouping of streams (Fig. 2), and the ANOSIM established minor differences (R=0.1, p=0.04) between the two sets of streams analyzed. Moreover, we did not find any significant relationships between any of the environmental variables considered and the probability of fish capture in either Uy (n=13, adjusted R^2=0.27, $F_{(8,4)}$=1.50, p<0.35) or Dk (n=20, adjusted R^2=0.37, $F_{(8,10)}$=2.34, p<0.35). Consequently, the environmental variables were excluded from further analysis.

Fish richness

The proportion of fish species richness captured with S-P in comparison with the estimation made by M-P was high in both regions (Uy: 90.2±2.3 [mean±SE], range 75.0–100 %; Dk: 99.3±0.7 %, range 85.7–100 %). The species richness estimation made by M-P comprised 1–9 and 12–32 species for Dk and Uy, respectively. In both countries, S-P and M-P data were strong and significantly related (Table 2, Fig. 3). The information extracted from the Akaike criterion analysis for the local and global models showed that the local model fitted the data best (Table 2). Moreover, the ANCOVA analysis revealed significant differences between the slopes of both regions ($F_{(1,\ 30)}$=10.16, p<0.01). New species caught using M-P (absent in the S-P capture) showed a significant relationship with fishing volume only in Uy (R^2=0.28, p=0.04), while no relationship with fishing area was observed.

The mean proportion of species richness captured with P compared with M-P was 87.2±3.4 (range 60–100 %) for Dk and 78.7±4.1 (range 58.8–100 %) for Uy (Fig. 4). The regression between P sampling and M-P sampling was significant for both countries (Table 3). The information extracted from the Akaike criterion analysis for the local and global models showed that the global model best fitted the data (Table 3). Moreover, the ANCOVA analysis revealed no significant differences between the slopes of both regions ($F_{(1,\ 30)}$=0.19, p=0.67). In both regions, new species caught using M-P (absent in the S-P capture in Uy+Dk) demonstrated a significant relationship with fishing area (R^2=0.26, p<0.001) but not with volume.

Table 2 Linear regression models predicting multiple-pass (M-P) richness from single-pass (S-P) electrofishing in streams from temperate (Dk) and subtropical (Uy) climates

Eq.no.	Model	Regression Parameters						Akaike		
		Region	Regression	n	Log a±CL 95 %	b±CL 95 %	r^2	Model	AIC	ΔAIC
1	Global	Uy+Dk	S-P vs. M-P	33	−0.01 (−0.04 to 0.02)	1.04 (1.01 to 1.07)	0.99***	Global	−139.6	7.6
2	Local	Uy	S-P vs. M-P	13	**0.27** (0.10 to 0.44)	**0.81** (0.67 to 0.95)	0.93***	Local	−131.9	
3		Dk	S-P vs. M-P	20	−0.003 (−0.02 to 0.01)	1.01 (0.98 to 1.04)	0.99***			

Eq. no. equation number, n number of streams ($\log_{10}$(M-P Richness)=$\log_{10} a+b^*$ ($\log_{10}$(S-P Richness))

AIC Akaike information criterion, Δ*AIC* Global model−Local model, *Global model* Uy+Dk, *Local model* one equation for each of the two countries.

*$p<0.01$, ***$p<0.0001$. $a\neq 0$ and $b\neq 1$ are highlighted in bold, t-test, $p<0.05$

Species composition

Relative abundance and presence–absence of each species versus the method (P, S-P and M-P evaluated by a Mantel test) exhibited high correlations for both countries (relative abundance: $0.98>R>0.77$; presence–absence: $0.99>R>0.74$, $p<0.0001$ in all cases; Table 4). The analysis of the 32 most common species from subtropical streams (present in at least three streams) and the ten most common species from temperate streams (present in at least three streams) revealed no significant differences in relative abundance between the three methods (Kruskall–Wallis test, $p>0.05$). In temperate streams, there was a marginally significant difference ($H_{2,9}=5.6$, $p=0.06$) for nine-spined stickleback (*Pungitius pungitius*) whose relative abundance was lower when using the P method, while rainbow trout (*Oncorhynchus mykiss*) was captured in only one stream and only with the P method.

Fish abundance

The expected density estimated by the M-P method was 1.3–5.2 and 3.3–33.3 in. m^{-3} for Uy and 0.1–4.9 and 0.3–11.6 in. m^{-3} for Dk. Not surprisingly, in both regions the proportion of the fish caught with P (Dk 63.7±9.6 %, Uy 53.8±6.1 %) and S-P (Dk 72.7±3.0 %, Uy 66.9±3.5 %) was clearly lower than the M-P abundance estimates. Nevertheless, in both temperate and subtropical streams the analysis of the abundance obtained with S-P and that estimated by M-P revealed a highly significant relationship (adjusted $R^2=0.96$, $F_{(1,18)}=481.14$ and adjusted $R^2=0.71$, $F_{(1,11)}=30.80$, $p<0.0001$, for temperate and subtropical streams, respectively). Moreover,

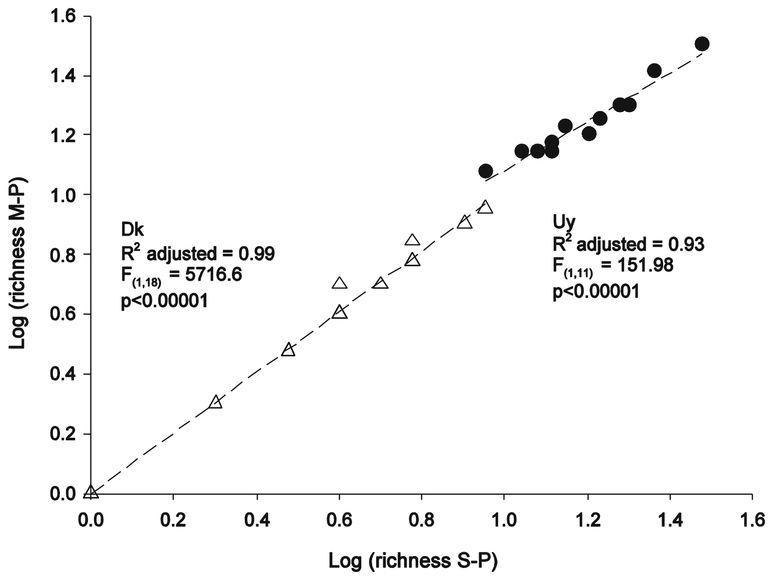

Fig. 3 Linear regressions between richness (number of species caught) using single-pass (*S-P*) and richness estimate by multiple-pass (*M-P*) methods in subtropical (*Uy*) and temperate (*Dk*) streams. *Triangles* represent temperate streams and *circles* subtropical streams

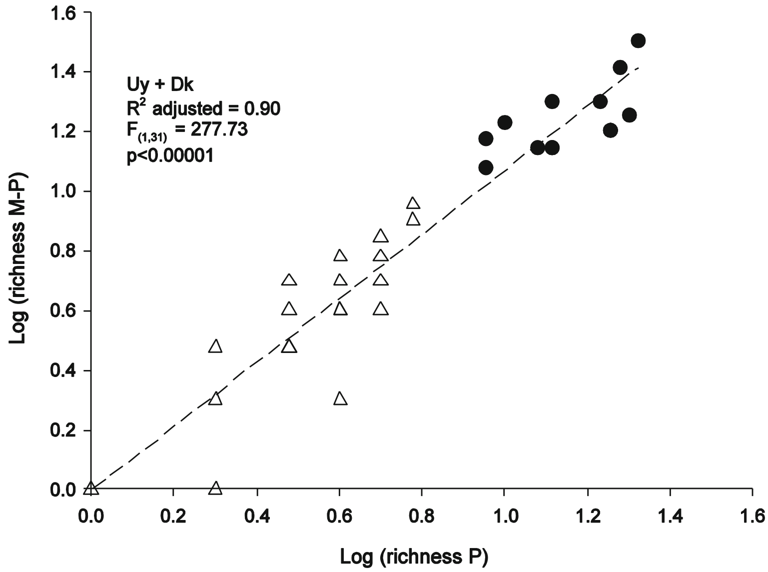

Fig. 4 Linear regressions between richness (number of species caught) using point fishing (*P*) and richness estimate by multiple-pass (*M-P*) methods in subtropical (*Uy*) and temperate (*Dk*) streams. *Triangles* represent temperate streams and *circles* subtropical streams

also the global analysis (Uy+Dk) showed a high correlation between the results of both methods (adjusted R^2=0.95, $F_{(1,31)}$=598.65) (Table 5). Using a relative scoring system (Δ_i) based on the Akaike information criterion, the global model performed better than the local models (ΔAIC=0.84; Table 5 and Fig. 5), and the ANCOVA analysis did not identify significant differences between slopes ($F_{(1,\ 30)}$=1.08, p=0.31).

In both temperate and subtropical streams, the analysis between the abundance obtained with P and the abundance estimated by M-P revealed a highly significant relationship, with a slightly higher variability than the relationship for S-P versus M-P (adjusted R^2=0.68, $F_{(1,18)}$=41.17, $p<$ 0.0001and R^2=0.35, $F_{(1,11)}$=7.55, $p<0.01$ for Uy and Dk, respectively; Table 6). Finally, higher correlation between both methods (adjusted R^2=0.78, $F_{(1,31)}$=113.59) appeared when performing the global analysis (Uy+Dk). Using the relative scoring system (Δ_i) based on the Akaike information criterion the global model performed best (ΔAIC=0.84; Table 6 and Fig. 6), and the ANCOVA analysis did not show significant differences between slopes ($F_{(1,\ 30)}$=0.67, p=0.42).

Size structure

The three methods provided a similar picture of the size distribution of the fish community; thus, no significant differences emerged between the three methods for any of the size classes analyzed in Dk or Uy (Kruskall–Wallis, $p<0.05$; Fig. 7).

Discussion

Contrary to the expectations based on previous results (e.g., Kruse et al. (1998); Scholten 2003), we did not

Table 3 Linear regression models predicting multiple-pass (M-P) richness from point (P) electrofishing in streams from temperate (Dk) and subtropical (Uy) climates

Eq.no.	Model	Regression Parameters						Akaike		
		Region	Regression	n	log a±CL 95 %	b±CL 95 %	r^2	Model	AIC	ΔAIC
4	Global	Uy+Dk	P vs. M-P	33	−0.01 (−0.12 to 0.11)	**1.07** (0.94 to 1.21)	0.90***	Global	−40.05	1.8
5	Local	Uy	P vs. M-P	13	**0.54** (0.06 to 1.03)	0.60 (0.19 to 1.03)	0.40*	Local	−38.25	
6		Dk	P vs. M-P	20	- 0.05 (−0.24 to 0.15)	1.14 (0.79 to 1.50)	0.70***			

AIC Akaike information criterion, Δ*AIC* Global model−Local model, *Global model* Uy+Dk, *Local model* one equation for each of the two countries, *Eq. no.* equation number, *n* number of streams ($\log_{10}$(M-P Richness)=$\log_{10} a+b$ * ($\log_{10}$(P richness))

*$p<0.01$, ***$p<0.0001$. $a\neq0$ and $b\neq1$ are highlighted in bold, t-test, $p<0.05$

Table 4 Mantel test for the relative abundance and presence–absence of each species caught using the three different methods (point, single and multiple-pass)

	Single-pass		Multi-pass	
Relative abundance analyses				
Temperate streams	Single-pass		Multi-pass	
Point	0.77	<0.0001	0.79	<0.0001
Single-pass			0.98	<0.0001
Subtropical streams				
Point	0.88	<0.0001	0.86	<0.0001
Single-pass			0.96	<0.0001
Presence–absence analyses				
Temperate streams	Single-pass		Multi-pass	
Point	0.75	<0.0001	0.74	<0.0001
Single-pass			0.99	<0.0001
Subtropical streams				
Point	0.85	<0.0001	0.84	<0.0001
Single-pass			0.97	<0.0001

The similarity matrices of relative abundance were calculated with the Bray–Curtis similarity index, and for the presence–absence data we used the Jaccard similarity index

find any effects of the environmental variables on the capture probability (i.e., fish abundance) calculated by the multiple-pass method. The following discussion therefore focuses on differences in efficiencies between the methods at global or local scale, when applicable.

With M-P as reference method, we found that the fishing methods tested differed in efficiency depending on the variable considered. We also found that the results did not necessarily depend on climatic and biogeographical region. Fish assemblage composition (measured as the relative abundance and presence/absence of each species) and body size distribution were equally well described by the three methods in both regions studied (i.e., significant and high correlation of the relative

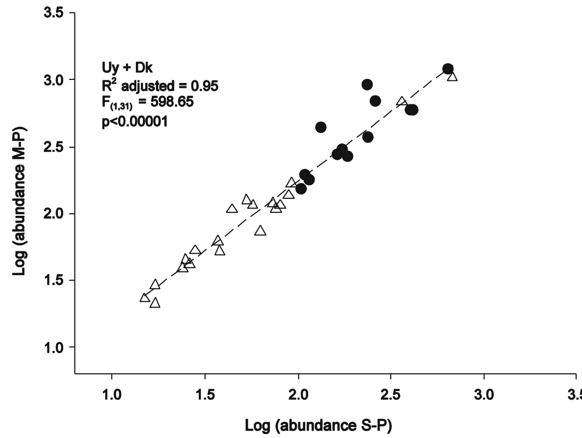

Fig. 5 Linear regressions between abundance estimated by single-pass (*S-P*) and abundance estimate by multiple-pass (*M-P*) methods in subtropical (*Uy*) and temperate (*Dk*) streams globally (Uy and Dk combined). *Triangles* represent temperate streams and *circles* subtropical streams

abundance and presence–absence matrix, Table 4, and no differences between the relative abundance of each size class, Fig. 7), which concurs with previous studies comparing S-P and M-P methods in wadeable streams (e.g., Sály et al. 2009). Our results also concur with those of Janáč and Jurajda (2007) who argued that P electrofishing suffices when community composition or body size distribution are the target variables. These findings collectively imply that results obtained by any of these three electrofishing methods can be directly compared without a priori transformation of the dataset. The consistency between the methods also has relevant practical consequences in that biological indices used in biomonitoring (e.g., multimetric index of biotic integrity [IBI]; Karr 1981, 1991), constructed using a series of fish community attributes related to the relative abundance of species, can be compared regardless of the method

Table 5 Linear regression models predicting multiple-pass (M-P) estimated abundance from single-pass (S-P) electrofishing in streams from temperate (Dk) and subtropical (Uy) climates

Eq.no.	Model	Regression parameters						Akaike		
		Region	Regression	*n*	log *a*±CL 95 %	*b*±CL 95 %	r^2	Model	AIC	ΔAIC
7	Global	Uy+Dk	S-P vs. M-P	33	0.16 (−0.02 to 0.35)	1.04 (0.95 to 1.13)	0.95***	Global	100.53	0.84
8	Local	Uy	S-P vs. M-P	13	0.32 (−0.57 to 1.21)	0.98 (0.60 to 1.36)	0.71***	Local	99.37	
9		Dk	S-P vs. M-P	20	0.21 (0.03 to 0.38)	1.00 (0.91 to 1.11)	0.96***			

AIC Akaike information criterion, Δ*AIC* Global model−Local model, *Global model* Uy+Dk, *Local model* one equation for each of the two countries, *Eq. no.* equation number, *n* number of streams ($\log_{10}$(M-P Abundance)=$\log_{10} a+b*$ ($\log_{10}$(S-P Abundance))

**p*<0.01, ****p*<0.0001. *a*≠0 and *b*≠1 are highlighted in bold, *t*-test, *p*<0.05

Table 6 Linear regression models predicting multiple-pass (M-P) estimated abundance from point (P) electrofishing in streams from temperate (Dk) and subtropical (Uy) climates

Eq.no.	Model	Regression parameters						Akaike		
		Region	Regression	*n*	log *a*±CL 95 %	*b*±CL 95 %	r^2	Model	AIC	ΔAIC
10	Global	Uy+Dk	P vs. M-P	33	**0.39** (0.02 – 0.077)	0.98 (0.78 – 1.18)	0.78***	Global	51.98	0.84
11	Local	Uy	P vs. M-P	13	0.80 (−0.62 – 2.22)	0.81 (0.17 – 1.46)	0.35***	Local	50.82	
12		Dk	P vs. M-P	20	0.48 (−0.02 – 0.99)	0.91 (0.60 – 1.22)	0.68***			

AIC Akaike information criterion, Δ*AIC* Global model−Local model, *Global model* Uy+Dk, *Local model* one equation for each of the two countries, *Eq. no.* equation number, *n* number of streams ($\log_{10}$(M-P Abundance)=$\log_{10} a+b$ * ($\log_{10}$(P Abundance))

*$p<0.01$, ***$p<0.0001$. $a\neq0$ and $b\neq1$ are highlighted in bold, *t*-test, $p<0.05$

applied. Also body size and length class of fishes, which have been widely proposed as good community attributes for evaluating the environmental status of freshwaters (e.g., Lopez and Pont 2011 and references therein), can be compared regardless of method.

According to our results, the attributes species richness and abundance obtained by the three fishing methods cannot be compared directly. To permit comparison we developed a series of reliable transfer equations to transform results obtained with the P and S-P methods to the more realistic description of the fish assemblage by the M-P method (Tables 5 and 6). Regarding richness (total number of fish species), we found the S-P method to be more efficient than the P method. Using the values estimated by the M-P method as references, the relationship between P and M-P demonstrated much larger variation and lower predictability than the relationship between S-P and M-P, but it was, though, sufficiently reliable to be transformed. Our results also revealed that the local model is the best for S-P to M-P transformation, while the global model is better for P transformation. Thus, our results showed that the total species number obtained using our transfer equations were more accurate for S-P than P and that local models fit better. Moreover, increasing the fishing area implies an enhanced risk of not detecting rare species when using the P but not the S-P method compared to the M-P method. On the other hand, with increasing volume also S-P becomes sensitive to rare species. For this reason, the validation of the transfer equations provided here applies only to the ranges of area and volume used for their calculation.

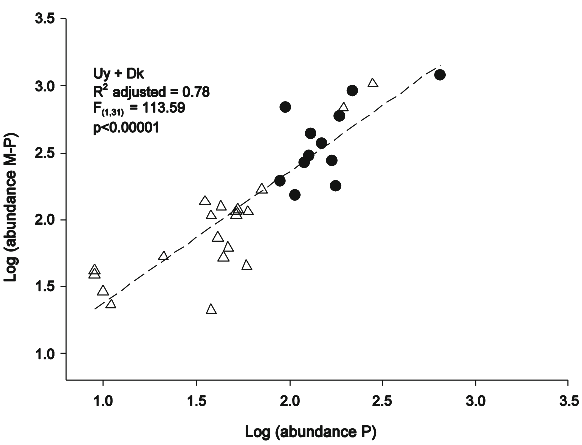

Fig. 6 Linear regressions between abundance estimated using point (*P*) and abundance estimated by multiple-pass (*M-P*) methods globally (Uy and Dk combined). *Triangles* represent temperate streams and *circles* subtropical streams

The accuracy of the models depended on the regional characteristics, such as species richness, and for transformation of data from S-P to M-P we suggest use of local transfer equations. When transforming a richer community (like our subtropical communities, species range: 12–32), we recommend use of the equation derived from the Uy data (Eq. 2, Table 2). For communities with low species richness (as our temperate communities, species range: 1–9) the equation derived from the Dk data (Eq. 3, Table 2) apparently performs better. If species richness obtained by P is to be transformed to M-P data, the global equation (derived from Uy+Dk data) appears to be the best choice (Eq. 4, Table 3). Application of these models allows comparison of results obtained by the different fish sampling methods. This may be particularly useful for monitoring purposes, since fish richness is frequently used as an indicator of the environmental quality of streams (e.g., Barrella and Petrere 2003; Scott and Hall 1997; Freeman and Marcinek 2006; Lyons 2006; Kanno et al. 2010; Zarucki et al. 2011). We

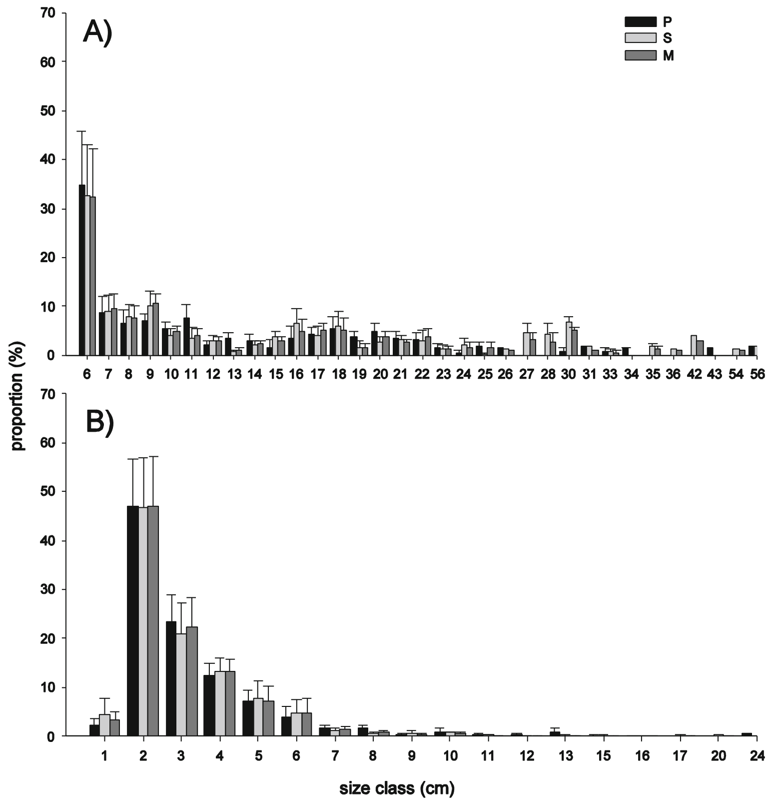

Fig. 7 Mean (SE) size class proportion from **a** temperate (n=8) and **b** subtropical (n=8) streams collected using three electrofishing methods: point (*P*), single-pass (*S-P*) and multiple-pass (*M-P*)

strongly recommend confirmation of the accuracy of the transfer equations via trial samplings permitting error estimations, particularly if transformation is carried out on data from other climatic regions.

Fish abundance derived from P data appeared to be least suitable for estimating fish abundance estimated by the M-P method compared to S-P data, but in both cases a highly significant relationship with M-P (Eqs. 7 and 10) was found, and both transformations are therefore sufficiently reliable to be applied. In this respect, the global model (Uy+Dk) seemed to be the best option. Our results concur with those of Kruse et al. (1998) who found that S-P would suffice to estimate abundance in streams with low fish density (maximum 0.4 individuals m^{-2}) and diversity (maximum five species), and we extend the validity of this pattern to streams with high fish densities (maximum 5.2 individuals m^{-2}) and high richness (maximum 32 species). It is important to emphasize that abundance data obtained with M-P estimations (directly or derived from P or S-P data using our equations) can later be transformed to density data (expressed in units of area or volume), thus allowing their comparison with any data irrespective of the stream area, volume or region where they were obtained. However, and similar to richness, the validation of the transfer equations provided here applies to the ranges of area and volume used for their calculation. If data on larger areas or volumes than those used in the present work are to be transformed, validation and/or adjustment for the specific location must be performed.

In conclusion, our results confirm that less demanding methods, such as P or S-P, are sufficiently accurate to be applied in a variety of research or monitoring scenarios in both temperate and subtropical streams with fish assemblages showing contrasting richness, size distribution and density. Also, considering that an enhanced sampling effort increases the handling time (implying longer processing time and lower probability of fish survival), logistic and ethical considerations lend extra support to the use of methods with lower sampling effort in stream surveys (in this case P or S-P electrofishing).

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