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Electrofishing efficiency in low conductivity neotropical streams: towards a non-destructive fish sampling method

L. ALLARD

Université Toulouse Paul Sabatier, CNRS, ENFA, UMR5174 EDB, Toulouse, France
Laboratoire Environnement de Petit Saut, Hydreco Guyane, Kourou Cedex, Guyane Française, France

G. GRENOUILLET

Université Toulouse Paul Sabatier, CNRS, ENFA, UMR5174 EDB, Toulouse, France

K. KHAZRAIE

Saul, Guyane Française, France

L. TUDESQUE

Université Toulouse Paul Sabatier, CNRS, ENFA, UMR5174 EDB, Toulouse, France

R. VIGOUROUX

Laboratoire Environnement de Petit Saut, Hydreco Guyane, Kourou Cedex, Guyane Française, France

S. BROSSE

Université Toulouse Paul Sabatier, CNRS, ENFA, UMR5174 EDB, Toulouse, France

Abstract Rotenone sampling is the most efficient method for assessing the fish assemblage structure and species abundance of low conductivity Amazonian streams. It does, however, cause fish mortality and disturb aquatic ecosystem. The aim of this study was to search for a non-destructive alternative. The efficiency of electrofishing was compared against complete removal using rotenone. This procedure was repeated in 12 streams dispersed throughout French Guiana to test for environmental and biological effects such as water conductivity, stream depth, fish family membership and body size. This study revealed that the efficiency of electrofishing was influenced by stream conductivity and stream depth, but not by fish family or body size. The electrofishing method might constitute an efficient alternative to using rotenone in smaller streams (below 25-cm depth and above 43 $\mu S\ cm^{-1}$), whereas in deeper and/or slightly conductive streams, rotenone still remains the only method able to provide a quick and comprehensive picture of the fish assemblage.

KEYWORDS: abundance, fish assemblage, French Guiana, richness, rotenone, stream depth.

Correspondence: Luc Allard, UMR5174 EDB (Laboratoire Évolution & Diversité Biologique), Université Toulouse Paul Sabatier, CNRS, ENFA, 118 route de Narbonne, F-31062 Toulouse, France (e-mail: luc.allard@hydrecolab.com)

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Introduction

The selection of an efficient sampling technique is a prerequisite to studying the structure of both plant and animal assemblages (Krebs 1999). This implies being able to obtain quantitative samples for all species and all size or age classes so as to determine the relative abundance of each species at a given site. For mobile animals, such as stream fishes, these data can only be acquired using active sampling methods that are characterised by low species and size selectivity (Murphy & Willis 1996). Among active sampling methods, direct underwater fish counts have been proposed (Thurow & Schill 1996); however, cryptic and nocturnal species cannot be observed although they are sometimes abundant, particularly in small neotropical streams where gymnotiforms and siluriforms account for a large part of the fish assemblage (Planquette *et al.* 1996; Le Bail *et al.* 2000). The use of toxicants like rotenone is hence frequently claimed to be the only efficient method for assessing the fish assemblage structure and species abundance in low conductivity streams that host high fish diversity, such as African and South American streams (Mahon 1980; Pardini 1998; Głowacki & Penczak 2005; Ibañez *et al.* 2007, 2009). This method is, however, destructive for the fauna, and although different procedures have been proposed to reduce the impact of rotenone (Mérigoux *et al.* 1998; Penczak *et al.* 2003), a non-destructive alternative would be welcome in setting up multiple sampling points at similar sites or obtaining samples in protected areas.

Electrofishing is the most widely used method for assessing fish assemblages in both temperate and tropical streams throughout the world (e.g. Angermeier & Davideanu 2004; Bozzetti & Schulz 2004; Breine *et al.* 2004; Santoul *et al.* 2005; Kennard *et al.* 2006; Tedesco *et al.* 2007; D'Ambrosio *et al.* 2008; Tomanova *et al.* 2013). It has the main advantage of permitting fish to be captured with a low risk of injury (VanderKooi *et al.* 2001; Snyder 2003). It is, however, sensitive to low water conductivity (Alabaster & Hartley 1962; Penczak *et al.* 1997). Several studies have tested the effect of water conductivity on fishing efficiency, and, although some authors consider electrofishing inefficient under values lower than 60 $\mu S\ cm^{-1}$ (Pusey *et al.* 1998; Beaumont 2002), others found no correlation between water conductivity and fishing efficiency from 30 to 400 $\mu S\ cm^{-1}$ (Alabaster & Hartley 1962; Penczak *et al.* 1997; Mazzoni *et al.* 2000). In the same way, experimentally increasing water conductivity by using massive salt inputs to the stream did not significantly increase fishing efficiency (Penczak *et al.* 1997). Finally, Esteves and Lobón-Cerviá (2001) and Motta Bührnheim and Cox Fernandes (2003) used electrofishing efficiently in small streams under very low water conductivities (10–30 $\mu S\ cm^{-1}$), and similar high efficiencies were reported for both African (Kadye & Moyo 2008) and European (e.g. the Garbet River in Villéger *et al.* 2012) low conductivity streams (below 20 $\mu S\ cm^{-1}$).

Aside from water conductivity, electrofishing efficiency also depends on other environmental factors such as river size and depth. Although electrofishing is known to be inefficient at depths greater than one metre and applicable in rivers <10 m wide, it is generally recognised that catch efficiency is higher in small streams than in large ones (Murphy & Willis 1996). In addition, fish characteristics can also affect electrofishing efficiency as large fish are more sensitive than small ones (Copp 1989; Cowx & Lamarque 1990), and species can have different sensitivities due to their behaviour, morphology and physiology (Zweimüller 1995; Reyjol *et al.* 2005).

The strong discrepancy in electrofishing efficiency reported in low conductivity streams might, therefore, have its roots in the multiple factors that may influence this fishing method. In this study, the efficiency of electrofishing in low conductivity neotropical streams was tested on a set of streams with various combinations of water conductivity, stream depth and width. The effect of fish characteristics, that is, family and body size, was also tested. The final aim of this study was to determine to what extent and in which streams electrofishing performed using a standard backpack electrofishing gear (EFKO FEG 3000), and a constant effort (two-pass electrofishing, constant progression speed) constitutes an alternative to the use of rotenone.

Materials and methods

Study area

The study was conducted during the dry season to ensure a stable water level in 12 low-order streams located throughout French Guiana. These streams were flowing in a primary forest environment (also called old-growth forest; see Hilbert & Wiensczyk 2007) and were not disturbed by human activity.

At each site, turbidity (mean 3.33 ± 1.05 NTU; range: 0.77–4.3), water temperature (mean 24.2 ± 0.41 °C; range: 23.8–24.9), pH (mean 6.49 ± 0.88; range: 5.05–7.15) and water conductivity (mean 41.58 ± 10.47 $\mu S\ cm^{-1}$; range: 21–50) were measured. pH and water temperature were measured with a WTW pH 3110 fitted with a WTW pH-Electrode SenTix 41; turbidity was measured with an Eutech Instruments Tubidimeter TN-100, and water conductivity was measured with a WTW 3110 conductometer fitted with a tetraCon 325 sensor. The range of physico-chemical characteristics encountered in these sites are representative of the Guiana shield streams that flow on poor soils developed on a granitic floor and hence exhibit low turbidity and conductivity (Hammond *et al.* 2007). The low overall conductivity as well as its low range is hence representative of the conditions found elsewhere in the Guiana shield.

Stream width was the mean value obtained from three to five transversal transect measurements according to the length of the section. Stream depth was an average derived from measurements taken each metre along each transversal transect. Between sites, pH, turbidity and water temperature did not show enough variation to affect the fishing methods, and no significant relationships between electrofishing efficiency and these variables were found (results not shown). pH, turbidity and water temperature were hence discarded from the analyses to avoid an undue decrease in the number of degrees of freedom in our statistical analyses. Moreover, stream width and stream depth were significantly correlated (Pearson correlation, $r^2 = 0.526$, $P < 0.01$), and stream width was hence removed from the analyses. Stream depth and water conductivity were thus used as the environmental descriptors for the sampling sites.

Fish sampling

At each site, a 12–62 m-long river section was isolated, using two fine mesh (4 mm) stop nets to keep fish from escaping from the sampling section and also from arriving from upstream or downstream. The length of the stream sections differed between streams based on streambed morphology (i.e. pools deeper than 1 m were not sampled) and streambed access (i.e. burden zones such as around fallen trees where distinguishing stunned fish was difficult were avoided). A two-pass electrofishing campaign was then conducted. Each electrofishing pass was conducted from the downstream net to the upstream net with the operator moving through the study site in a zig-zag fashion. One operator was managing the anode, and the two others collected fish using 2-mm mesh dip nets. One anode was considered sufficient in regard to stream width that did not exceed 5 m in all but one site, which presented a wide shallow sandy channel and was 8.9 m wide. Moreover, water depth was less than 50 cm in all sites (mean 30 ± 11.7 cm; range: 4.1–46.4 cm), and water clarity was sufficient to collect all stunned fish from the surface to the bottom. The speed progression was about 2 m^2 min^{-1}, so as to ensure a constant sampling effort. All stunned fish were collected and stored in a separate container for each pass. Fish injury or fish mortality induced by electrofishing was never observed, whatever the considered site or species.

The electrofishing apparatus was a FEG 3000 (EFKO, Germany) backpack. It is a 3000 W, 300–500 V, DC electrofishing unit which is commonly used for fish studies (e.g. Denic & Geist 2009; Turek *et al.* 2010). A 500 V setting was used in all sites as low conductivity (ranging from 21 and 50 μS cm^{-1} according to the sites) necessitated using the maximal strength. It should nevertheless be noticed that less powerful apparatus (e.g. FEG 1500) also delivering 500 V but lower power (1500 W) was considered as efficient to collect a wide range of fish species under very variable conductivities (e.g. from 12 to 350 μS cm^{-1}; Villéger *et al.* 2012). A 3-m copper cathode and a 20-cm-diameter ring anode were used, because a large amount of the fish fauna is small sized (mean fish body size: 49 ± 55 mm, range 10–390 mm), making large anodes inefficient for the capture of a substantial part of the fish. This was confirmed by preliminary tests using 10-, 20- and 40-cm ring anodes. Those tests showed that a 20-cm ring anode provides the best compromise between increasing the electric field intensity using a small anode and increasing the size of the electric field using a large anode (results not shown). Once this was set, the same settings were used in all sites to allow sites comparisons.

Modifying the characteristics of the electrofishing apparatus or comparing different electrofishing devices was avoided, as the aim was to test the fishing efficiency of a standard electrofishing device. The most powerful backpack device developed by EFKO was used and its efficiency was comparable to most other brands (Smith & Roots and Dream Electronique propose equivalent materials with maximal backpack power peaking at 2800 and 2300 W, respectively). More powerful electrofishing equipment might have been useful under the low conductivities found in Guiana streams, but this would have necessitated using a static generator, which would be difficult to use in a tropical forest environment where some sites are only accessible on foot, often reached by long hikes through the forest.

After the two-pass electrofishing, all the fish remaining in the stream section were collected by releasing a small quantity of rotenone (PREDATOX®: a 6.6% emulsifiable solution of rotenone extracted from *Derris elliptica* by Saphyr, Antibes, France) a few metres upstream from the first stop net. This permitted the collection of all of the remaining fishes in the enclosed area. Particular attention was paid to releasing as little toxicant as possible to avoid fish mortality downstream from the section studied. Moreover, study sections were located just upstream from a confluence to ensure sufficient dilution of the rotenone downstream from the study section and hence avoid undue fish mortality. For a complete description of the rotenone sampling method, see

Mérigoux *et al.* (1998). The use of rotenone permitted to collect all of the fish remaining in the study section as rotenone is known to be efficient in conducting total fish removals (Penczak *et al.* 1997; Mérigoux *et al.* 1998; Głowacki & Penczak 2005).

Fish species were then identified according to Planquette *et al.* (1996), Keith *et al.* (2000) and Le Bail *et al.* (2000, 2012). Some specimens from each species were collected and fixed in a 5% formaldehyde solution for taxonomic confirmation. All fish captured during each electrofishing pass and in the final rotenone-based removal were identified, counted and measured to the nearest mm. Standard length was preferred to total length so as to avoid bias due to particular fish morphologies (e.g. Loricariidae that can have caudal filaments). The mean body length per species and per site was then calculated.

Analytical methods

As the two-pass electrofishing method did not allow for an exhaustive fish collection, fish abundance and fish richness were extrapolated using dedicated estimation methods. Fish abundance for each species and each site was calculated using the Carle and Strub (1978) method, which is commonly used to extrapolate species abundances from repeated electrofishing efforts (Meador *et al.* 2003; Rosenberger & Dunham 2005; Hedger *et al.* 2013). In a few cases (43 cases of a total of 208 = 20.6%) that account for rare species, the number of individuals for a given species was greater during the second pass than during the first one; the total number of fish captured was thus used as an estimation of the abundance for that species.

Species richness per site was estimated using the Chao estimator (Chao 1984; Shen *et al.* 2003). It is commonly used to determine the richness of organisms in natural environments based on repeated quantitative samples (Brose *et al.* 2003; Martínez-Sanz *et al.* 2010).

The richness and abundance estimations per site (using the Chao and Carle & Strub methods, respectively) derived from the two-pass electrofishing effort were then compared to the total fish richness and abundance at each site derived from total removal (i.e. all of the fish collected during the two electrofishing passes and from the final rotenone-based catch). The ratio between fish richness estimated using Chao on the two-pass electrofishing data and the total fish richness of the site therefore provided a measure of the electrofishing efficiency in determining fish richness (ELEr). In the same way, the ratio between the fish abundance estimated using Carle and Strub for each species from the two-pass electrofishing data and the total fish abundance for the same species at the site provided a measure of the electrofishing efficiency to determine the fish abundance for each species (ELEsp). Finally, the electrofishing efficiency in determining overall fish abundance per site (ELEab) was defined as the ratio between the sum of the fish abundances estimated by electrofishing for the different species (using Carle and Strub method) and the total number of fish collected from each site after the two electrofishing passes and the final rotenone-based removal.

ELEsp, ELEr and ELEab varied between 0 and 1, and higher values indicated the higher efficiency of the electrofishing method. In a few cases (4 of 208), ELEab was >1 indicating that the Carle and Strub estimation predicted more fish than the number actually caught after the total rotenone removal. In such a case, the value was considered as 1.

The relationship between environmental parameters (i.e. water conductivity and stream depth) and the two efficiency metrics measured at the assemblage level, namely ELEr and ELEab, were first tested. Then, at the species level, the effect of environmental variables (i.e. water conductivity and stream depth) and of the biological characteristics of the fish (i.e. mean fish body size per species, fish family for each species and implicitly fish position in the water column) on the electrofishing efficiency measured per species and per site (ELEsp) was tested.

Generalised linear mixed models (GLMM) were built to test the effect of environmental variables and biological characteristics of the fish on electrofishing efficiency. In these models, ELEsp was the dependent variable, and the water conductivity, stream depth and log of mean fish body size per species were the continuous predictors. Mean fish body size per species was log-transformed to fit normality. Fish family and sampling area were used as random factors. The GLMM method controls for the potential confounding effects between continuous predictors and random factors. It hence provides a pure effect of continuous predictors, independently from the effect of random factors. Finally, as electrofishing efficiency can also be affected by fish family membership, a second GLMM where ELEsp was the dependent variable, and the water conductivity, stream depth and fish family were the continuous predictors, was built. In this model, log of mean fish body size per species and sampling area were used as random factors. Fish family membership was here used as a surrogate of fish species membership, making the hypothesis of functional conservatism within families (Ibañez *et al.* 2007; Wiens *et al.* 2010). Indeed, considering fish species membership in our GLMM model implies the introduction of 81 additional parameters (corresponding to the 81

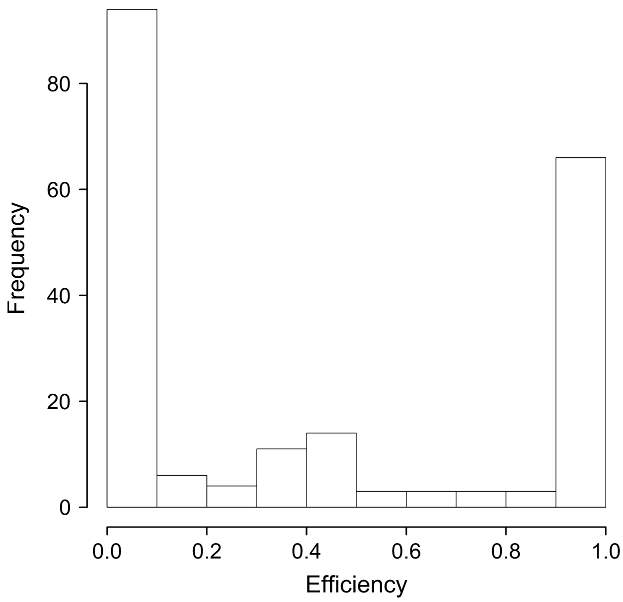

Figure 1. Histogram showing the distribution of electrofishing efficiencies. Electrofishing efficiencies were calculated for each species at each sampling site (i.e. ELEsp), giving rise to a total of 208 ELEsp values.

species) in the models, which would cause a severe decrease in degrees of freedom and hence greatly affect models reliability.

Finally, three ELEsp efficiency classes were used to determine which type of site in terms of environmental variables (i.e. stream depth and water conductivity) can efficiently be sampled using electrofishing: low efficiency (<10%), high efficiency (more than 90%) and intermediate efficiency. Those classes were determined according to the distribution of the ELEsp values (see Fig. 1) that showed two groups (high and low efficiency). The class between 10 and 90% represented a transition between the two extremes, without any particular trend among this group. Moreover, the three classes accounted for a similar number of observations making them comparable. Each of these three classes were then characterised according to water conductivity and stream depth. Student's *t*-tests were performed to test for differences between classes.

All analyses were developed using R environment software v 2.13.0 (R Development Core Team 2011) using the package vegan (Oksanen *et al.* 2013).

Results

When the overall assemblage metric estimations were considered, the efficiency of the two-pass electrofishing technique to estimate abundance (ELEab) and richness (ELEr) significantly decreased with stream depth (Pearson correlation $r^2 = 0.765$, $P < 0.01$ and $r^2 = 0.355$, $P = 0.04$ for ELEab and ELEr, respectively). Fish abundance and, to a lesser extent, fish richness were estimated for shallow sites with ELEab values higher than 0.8 and ELEr values higher than 0.6 (Fig. 2a, c). Water conductivity significantly increased ELEab ($r^2 = 0.455$, $P < 0.05$), but under the highest water conductivity values, ELEab remained extremely variable (Fig. 2b). Contrary to ELEab, ELEr was not significantly related to water conductivity ($r^2 = 0.055$, $P = 0.46$, Fig. 2d).

At the species level, the estimation of species abundance (ELEsp) was also significantly related to the two environmental variables, stream depth and water conductivity (Table 1). As for the assemblage metrics, ELEsp increased with water conductivity and decreased with stream depth. This was consistent for the two GLMM models, and the biological characteristics of the fish (i.e. body size, fish family) did not significantly influence the model results and hardly affected the contribution of the two environmental parameters to the model (Table 1). This also testifies that fish position in the water column did not affect fish catchability (Table 1).

Scattering the ELEsp showed that fishing efficiency was very low (<10%) in more than 50% of the cases, whereas it was high in approximately 30% of the cases. The 20% remaining represented a fishing efficiency higher than 10% and lower than 90% (Fig. 1). Considering the three efficiency classes (i.e. low: >10%, intermediate: 10–90% and high: >90%) showed that electrofishing efficiency was high above 43 μS cm^{-1} and at sites where mean stream depth was lower than 25 cm (Fig. 3). On the contrary, sites where water conductivity was below 34 μS cm^{-1} and/or mean stream depth was above 30 cm could not be efficiently sampled using electrofishing. Considering individual species confirmed that fishing efficiency was high in conductive (>43 μs cm^{-1}) and shallow (<25 cm) sites, although electrofishing efficiency differs according to species. It should, however, be noted that the limited number of individuals caught for some species does not allow further interpretations at the species level (see Appendix S1).

Discussion

Although electrofishing is among the most frequently used methods for the assessment of stream fish assemblages around the world, the range of environmental conditions for its use vary according to the study. It is indeed frequently considered inefficient in low conductivity streams (Fisher & Brown 1993; Penczack *et al.* 1997; Beaumont 2002), whereas some studies have shown it can remain effective under low water conduc-

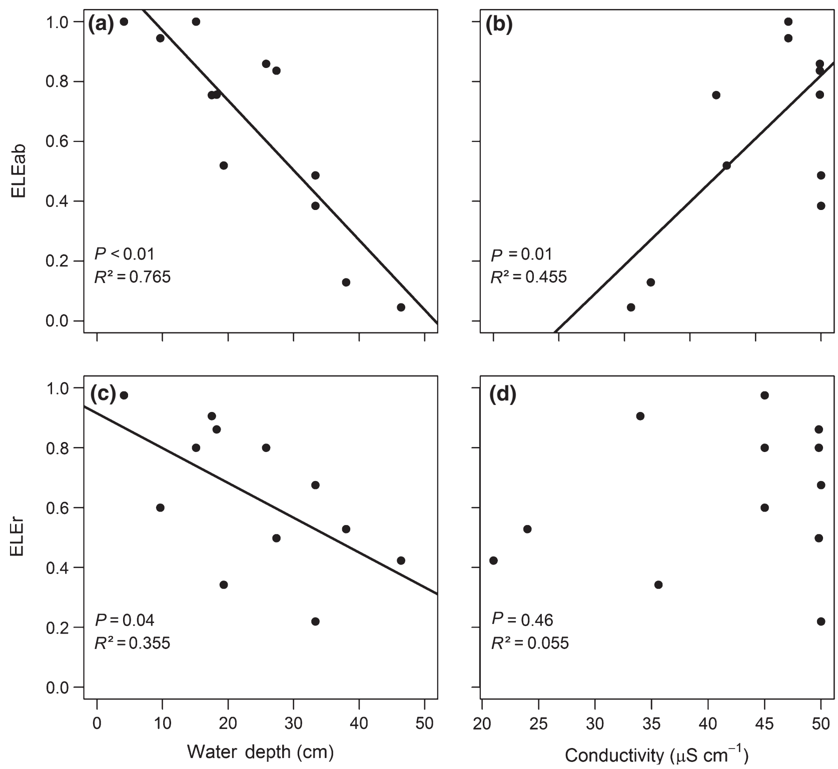

Figure 2. Electrofishing efficiency vs. stream depth and water conductivity in estimating fish abundance (a, b) and richness (c, d). Abundance and richness were estimated using Carle and Strub (CS) and Chao estimators, respectively. Data were fitted using a linear regression (R^2 and P values are given on each panel).

tivity (10–60 μS cm^{-1}) (Esteves & Lobón-Cerviá 2001; Motta Bührnheim & Cox Fernandes 2003). Such inconsistency probably has its roots in the potential interplay between physical, environmental and biological features. In this study, electrofishing efficiency was significantly affected by environmental characteristics (i.e. water conductivity and stream depth), but not by the biological characteristics of the fish (i.e. body size, family and fish position in the water column) (Table 1). It should also be noted that stream depth had a more pronounced effect on the overall abundance metrics (i.e. overall richness and abundance) than conductivity.

Stream depth is one of the main limiting factors in studies based on electrofishing (Alabaster & Hartley 1962; Pusey *et al.* 1998). Electrofishing is usually considered as efficient below a depth of one metre, which is consistent with the diameter of the stunning distance around the anode (Bohlin *et al.* 1989; Beaumont 2002; Meador *et al.* 2003). Under those optimal conditions, the entire water column is sampled from the surface to the bottom of the stream, which probably lowers the potential for fish escape as the vertical movements of fish do not allow them to avoid the stunning area. Here, stream depth was below the 1-m limit as it was always <0.5 m, and water clarity was sufficient to detect all of the stunned fish from the surface to the bottom of the stream. It can, therefore, be hypothesised that the diameter of the stunning area is lower in Guianese streams compared with more conductive streams found elsewhere in the world. This was verified (although not quantified) during field sampling as individual fish escaping less than one metre from the anode was frequently observed. Increasing stream depth and water volume (stream depth and width being highly correlated at our sites) therefore increased the probability that fish would escape and thus decreased our ability to estimate both the richness and abundance of fish (Fig. 2).

The effect of stream depth probably acts together with water conductivity, which is usually considered as the main limiting factor for electrofishing methods (Alabaster & Hartley 1962; Pusey *et al.* 1998). It should, however, be noted that a positive significant relationship between water conductivity and electrofishing efficiency was only found for overall fish abundance and not for species richness (Fig. 2b, d). Hence, as testified by the GLMM analysis, the ability to estimate the abundance of each species at each site was determined by the combination of stream depth and water conductivity. The two

Table 1. Results of the generalised linear mixed models (GLMM) assessing the effect of (a) mean fish size per species, water conductivity and stream depth and (b) fish family, water conductivity and stream depth on the electrofishing efficiency for each species at each site. Fish position in the water column is indicated as benthic (B) or pelagic (P). Only a few families gather both pelagic and benthic species (P/B)

(a)	Estimate	*Z* value	*P* value
Log (fish size)	−0.002	−1.257	0.209
Water conductivity	0.053	5.907	<0.001
Stream depth	−0.035	−4.826	<0.001

(b)	Fish position	Estimate	*Z* value	*P* value
Anostomidae	P	−0.874	0.000	1.000
Aspredinidae	B	1.665	0.003	0.997
Auchenipteridae	P	1.594	0.003	0.998
Callichthyidae	B	1.463	0.003	0.998
Cetopsidae	B	1.496	0.003	0.998
Characidae	P	1.563	0.003	0.998
Characidiidae	B	1.662	0.003	0.997
Cichlidae	P/B	1.567	0.003	0.998
Curimatidae	P	1.488	0.003	0.998
Erythrinidae	P/B	1.593	0.003	0.998
Gymnotidae	B	1.593	0.003	0.998
Hemiodidae	P	0.462	0.003	1.000
Hemiodontidae	B	0.799	0.003	1.000
Heptapteridae	B	1.460	0.003	0.998
Hypopomidae	B	1.554	0.003	0.998
Lebiasinidae	P	1.611	0.003	0.998
Loricariidae	B	1.617	0.003	0.997
Pseudopimelodidae	B	−0.191	0.003	1.000
Rivulidae	P/B	1.604	0.003	0.998
Sternopygidae	B	1.479	0.003	0.998
Synbranchidae	B	1.659	0.003	0.997
Trichomycteridae	B	1.517	0.003	0.998
Water conductivity		0.047	6.337	<0.001
Stream depth		−0.040	−5.770	<0.001

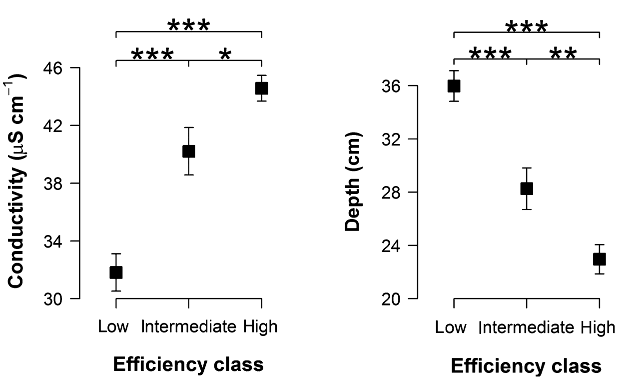

Figure 3. Water conductivity and stream depth for three classes of electrofishing efficiency (ELEsp). Mean values and standard errors are shown; stars indicate the significance of Student's *t*-tests between classes (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

GLMM models measured a similar effect (considering the significance, direction and magnitude) of stream depth and water conductivity, testifying to the robustness of these effects on electrofishing efficiency. The decrease in electrofishing efficiency when water conductivity decreases can probably be linked to a reduction in the stunning diameter, which enables the fish in deeper streams to escape (Beaumont 2002).

It should, moreover, be noted that despite experimental evidence on the effect of fish behaviour, habitat preference, body size and physiology (Sternin *et al.* 1976; Bohlin *et al.* 1989; Meador *et al.* 2003), no significant effect of fish body size or fish position in the water column on electrofishing efficiency was detected (Table 1). This means that under the appropriate environmental conditions, the entire fish assemblage can be sampled using electrofishing without a significant family membership effect. This shows that when water conductivity is sufficiently high and the stream sufficiently shallow, it is possible to obtain a relevant picture of the entire fish assemblage, including overall descriptors such as fish richness and abundance as well as more precise information on the structure of the fish assemblage.

Considering a 90% catch efficiency as a reasonable threshold providing a relevant picture of the fish assemblage means that the electrofishing device, settings and fishing protocol used can efficiently be employed above 43 $\mu S\ cm^{-1}$ and in streams shallower than 25 cm (Fig. 3). This means that only headwater streams with sufficient water conductivity can be sampled using electrofishing. Despite strong limitations to the extent of the applicability of electrofishing in French Guiana, electrofishing has been shown as an efficient alternative to rotenone-based sampling in those streams. This opens up research opportunities in these poorly known and rarely studied ecosystems where non-destructive approaches can now be designed using electrofishing. This might permit fish inventories to be conducted in pristine, protected areas (e.g. see Mol *et al.* 2007; Brosse *et al.* 2013), as well as to follow changes in fish assemblages through time in those areas that remain little impacted by human activity (Thoisy *et al.* 2010). From a management point of view, this might also permit us to develop the repeated sampling techniques needed to monitor the responses of stream ecosystems under pressure related to human activity such as gold mining, which is rapidly developing in the Guiana shield (Hammond *et al.* 2007) and which strongly affects some Guianese streams (Brosse *et al.* 2011).

Finally, it should be noted that these conclusions are dependent on the electrofishing device and settings used. The choice to test the efficiency of electrofishing using a standard device (although it was the most powerful backpack electric fishing gear available), considered as efficient for the collection of fish in a wide range of stream conditions (Denic & Geist 2009; Turek *et al.* 2010), was deliberate. Electrofishing efficiency might hence be increased using different devices and settings. The results indicate that further studies are needed, aiming at developing an electrofishing apparatus designed to sample fish more efficiently in low conductivity tropical streams. For example, it would be useful to test various settings combining current intensity and waveform, as well as anode and cathode size, as proposed by Lamarque and Gosset (1978) and Beaumont (2002).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Mean efficiency of capture per species (ELEab) under different conductivity and water depth conditions. *N* is the total number of fish individuals collected for each species.