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# Spatially intensive sampling by electrofishing for assessing longitudinal discontinuities in fish distribution in a headwater stream

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ABSTRACT

Spatially intensive sampling by electrofishing is proposed as a method for quantifying spatial variation in fish assemblages at multiple scales along extensive stream sections in headwater catchments. We used this method to sample fish species at 10-m$^2$ points spaced every 20 m throughout 5 km of a headwater stream in France. The spatially intensive sampling design provided information at a spatial resolution and extent that enabled exploration of spatial heterogeneity in fish assemblage structure and aquatic habitat at multiple scales with empirical variograms and wavelet analysis. These analyses were effective for detecting scales of periodicity, trends, and discontinuities in the distribution of species in relation to tributary junctions and obstacles to fish movement. This approach to sampling riverine fishes may be useful in fisheries research and management for evaluating stream fish responses to natural and altered habitats and for identifying sites for potential restoration.



## 1. Introduction

Landscape perspectives in riverine ecology have increasingly been recognized in the last 30 years (Pringle et al., 1988; Schlosser 1991; Johnson and Host, 2010), leading to the concept of the "riverscape" (Malard et al., 2000; Ward et al., 2002; Wiens, 2002). This concept considers the patchy nature of river systems and emphasizes the critical importance of considering the spatial and temporal context of riverine organisms and their habitat. This contextual dependency, expressed in the serial discontinuity concept (Ward and Stanford, 1995) and the concept of the river discontinuum (Poole, 2002), necessitates spatially explicit approaches. Fausch et al. (2002) highlighted the importance of (1) developing "a continuous view of a river. . .to understand how processes interacting among scales set the context for stream fishes and their habitat", and (2) employing sampling approaches that enable the quantification of patterns in fish distribution at multiple scales.

The most commonly used method for sampling fish in rivers is electrofishing (Cowx and Lamarque, 1990; Dunham et al., 2009). For small- to medium-sized rivers, multiple-pass removal electrofishing performed on a relatively short river reach is the standard method because it provides an accurate assessment of fish abundance (Carle and Strub, 1978). Because of the precision of local estimates that removal electrofishing provides, this sampling strategy is frequently recommended in large-scale monitoring programs, like those implemented within the European Water Framework Directive (CEN, 2003). However, this approach is typically conducted at relatively few discrete sites separated by >1 km of stream, leaving large portions of the river unsampled. Although regional fish patterns can be inferred using cumulative data from discrete sampling locations (Smith and Jones, 2005) and predictive statistical modeling, there may be a knowledge gap between local scales (i.e., the scale of a sampled site: 100–500 m) and intermediate scales targeted by management plans (5–10 km), (Meador et al., 2003).

Spatially intensive approaches to sampling are needed to assess variability in fish distribution in response to instream habitat structure and spatial stream discontinuities of natural or anthropogenic origin. Close spacing of samples longitudinally along the stream provides the resolution necessary to describe spatio-temporal heterogeneity in the physical stream environment (White et al., 2014) and to localize discontinuities in stream fish distribution caused by chemical, physical and thermal factors (Bateman et al., 2005; Baxter, 2002). Such approaches have been used to assess discontinuous fish distributions (Angermeier et al., 2002; Angermeier and Smogor, 1995) at tributary junctions (Kiffney et al., 2006) and below dams (Brenkman et al., 2012). Various methods to spatially intensive sampling have been employed to quantify spatial

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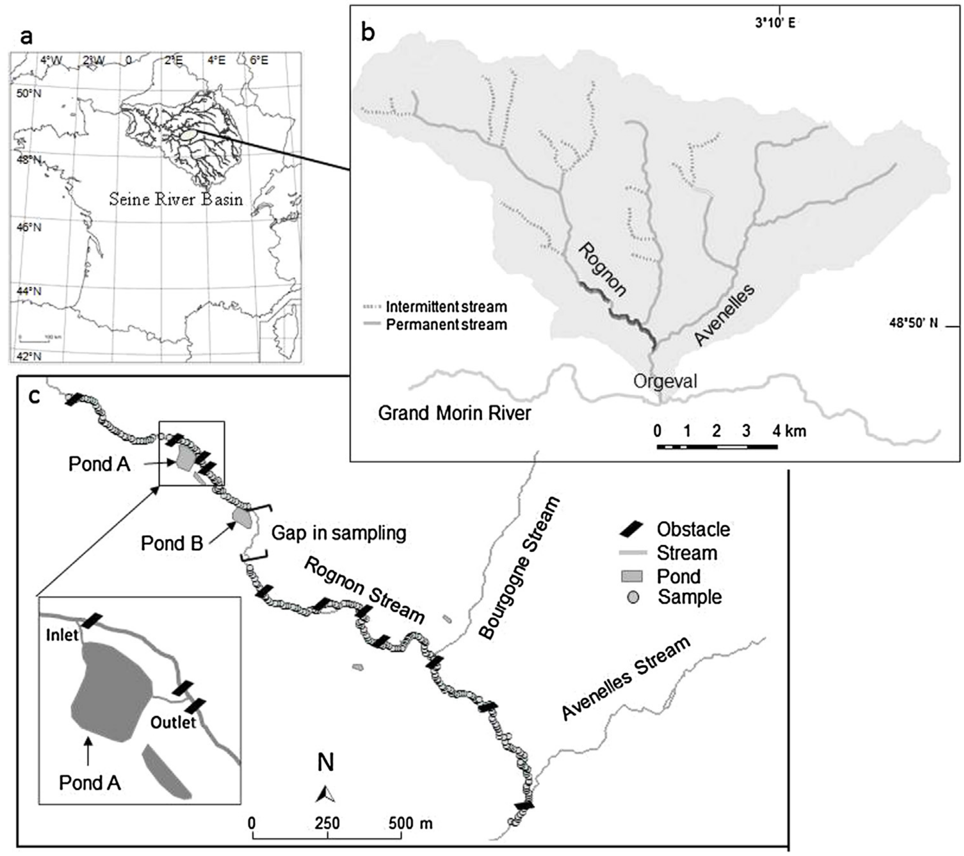


**Fig. 1.** (a) Study area in the Seine River Basin, France. (b) Orgeval experimental catchment (shaded in grey) and sampling reach on the Rognon stream (shaded in dark grey). (c) Spatially intensive sampling by electrofishing (SIS) in the Rognon stream. A detail of pond A is provided, with locations of obstacles and connected inlet and outlet. Note spatial gap (400 m) in sampling (brackets) due to inaccessible private property surrounding pond B.

heterogeneity in rivers and stream fish distribution. For example, low-level helicopter flights were used to survey salmon nests visually (Isaak et al., 2007) and shore-based visual estimation methods were tested to count age-0 Bonneville cutthroat trout (White and Rahel, 2008). Extensive snorkel surveys (Kiffney et al., 2006; Mullner et al., 1998) and single-pass electrofishing (Bateman et al., 2005) have been used to provide the opportunity to evaluate species distribution at both small and large scales, from metres to kilometres (Fausch et al., 2002; Gresswell et al., 2006; Lawrence et al., 2012; Torgersen et al., 2006). Snorkel surveys provide reliable estimates of fish abundance and community composition, particularly in remote locations and in rivers that are too large and deep for electrofishing (Chamberland et al., 2014). However, snorkeling is generally not effective for detecting cryptic benthic species (Macnaughton et al., 2014; Plichard et al., 2016) and for sampling streams that are shallow or turbid. The effectiveness of single-pass backpack electrofishing for sampling fishes has been assessed in many studies (Bateman et al., 2005; Bertrand et al., 2006; Meador et al., 2003; Reid et al., 2008). Brenkman et al. (2012) used this method to highlight bull trout (*Salvelinus confluentus*) 'hotspots' (i.e., where the species was locally abundant) and fish-habitat relationships prior to dam removal. The expense of spatially continuous single-pass electrofishing may preclude sampling long river segments. To overcome this limitation, fractional sampling can be conducted randomly or systematically without altering the accuracy of fish abundance estimates (Mitro and Zale, 2000). For instance, Torgersen and Close (2004) used a nested electrofishing sampling design at fine (metres) and coarse (kilometres) spatial scales to quantify spatial patterns in larval Pacific lamprey abundance along a 55-km river section.

Point abundance sampling by electrofishing (PASE) is a fractional sampling design that is employed to collect fish at many small samples as opposed to relatively few large samples (Nelva et al., 1979; Persat and Copp, 1990). The PASE approach is similar to other fractional sampling methods, such as quadrat sampling (Williams et al., 2002), the abundance index (Prévost and Nihouarn, 1999), and habitat unit sampling (Lamouroux et al., 1999). Relative to multiple-pass removal by electrofishing, the PASE method is more cost-effective and has less potential for causing injury and mortality to fish (Copp, 2010). Commonly used to sample 0+ fish (Copp and Garner, 1995; Scholten, 2003; Tales and Berrebi, 2007), its effectiveness has been shown for adult fish at the population or assemblage level (Laffaille et al., 2005; Pretty et al., 2003; Teixeira-de Mello et al., 2014; Tomanova et al., 2013).

The goal of this study was to propose and test a new sampling method in accordance with the riverscape approach (*sensu* Fausch et al., 2002) for assessing the distribution and discontinuities patterns in stream fish assemblages along a stream section (5 km) in a human-influenced headwater catchment. Specifically, we used systematic, spatially intensive sampling (SIS) based on PASE and spatial statistical analysis to quantify longitudinal patterns and spatial variability in stream fish abundance, species richness, and aquatic habitat at multiple scales.

## 2. Methods

### 2.1. Study area

The study area was located in the headwaters of the Orgeval catchment (104 $km^2$) in the Seine River basin, 70 km east of Paris,