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Bias in estimates of electrofishing capture probability of juvenile Atlantic salmon

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ABSTRACT

We evaluated the effect of the total number of passes used, and the application of block nets, on multi-pass electrofishing removal sampling for estimating juvenile Atlantic salmon (*Salmo salar* L.) abundance and body size distribution. Sites within selected salmon-bearing Norwegian rivers were enclosed by block nets and electrofished for multiple passes (range: 7–13), and capture probabilities and abundances were estimated using the Carle and Strub removal method. We examined for different body size classes: (1) bias in the estimated capture probability and abundance associated with the number of passes used; (2) the potential for bias to be minimized by the use of block nets; and (3) electrofishing-induced mortality. We found that the capture probability estimate was strongly dependent upon the number of passes used, tending to decline with successive pass, with the effect depending on size class. Thus, estimates made using the traditional three-pass approach would result in underestimates of abundance, and biased estimates of size distribution. Smaller juveniles were both more likely to impinge on the block nets and more likely to experience mortality than larger juveniles. Mortality was greatest when water temperature was high (> 18 °C). Our findings indicate that quantitative electrofishing for small juveniles may be unreliable, and that electrofishing at high temperatures should be avoided due to potential high mortality.

1. Introduction

Electrofishing with portable gear is a standard method for sampling fishes in freshwater (Anonymous, 2003; Vehanen et al., 2010; Argillier et al., 2013), and is the most commonly used method for sampling juvenile salmonids in streams and moderately sized rivers (Bohlin et al., 1989; Korman et al., 2009). The main reason for the widespread use of electrofishing is that it represents a simple, inexpensive and cost-efficient way to catch riverine fishes.

The objectives of electrofishing surveys range from simply determining the prevalence of fishes or characterizing fish species assemblages to estimating abundances by size- or age-group. However, electrofishing may produce biased estimates of these population characteristics because some fish may avoid capture, particularly if only a single pass is used (Arnason et al., 2005; Bateman et al., 2005). For example, electrofishing capture probability has been observed to increase with increasing body size, both in salmonids (Peterson et al., 2004; Korman et al., 2009; Saunders et al., 2011) and in other fishes (Dauwalter and Fisher, 2007; Hense et al., 2010) so there is potential to over-sample large individuals and produce unreliable estimates of the population body size distribution. A multi-pass removal approach, in which the change in numbers captured on successive electrofishing passes provides estimates of capture probability, may increase the accuracy of abundance estimates (e.g., Zippin, 1958; Carle and Strub, 1978). However, such an approach relies upon several assumptions. Firstly, it is assumed that the probability of capture is constant over successive passes for all fish. Secondly, it is assumed that sampling is conducted on a closed population – i.e. no fish can leave or enter the fished site during sampling. These two assumptions are often violated.

Capture probability has often been observed to decline with successive passes (Borgstrøm and Skaala, 1993), which may result in biased estimates. For example, a simulation study by van Poorten et al. (2017) found that no single removal method performed robustly under conditions of non-constant capture probability, generally causing an underestimate of abundance due to vulnerable fish being captured earlier. Even when assumptions are not violated, removal estimates are only reliable if sufficient numbers of individual fish are present within the fished area – Riley and Fausch (1992) for example estimated that a

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minimum sample size of 30 individuals within the site was required. A large proportion of the population must be captured to obtain a precise estimate of the population: for example, Zippin (1958) estimated that for a population of 200 individuals 75% would have to be captured to achieve a coefficient of variation of 10% for the abundance estimate.

Juvenile fish are motile so the assumption of a closed population is often violated due to immigration or emigration, resulting in biased estimates. Additional emigration may be initiated due to a flight response of the fish to the disturbance involved in electrofishing (Young and Schmetterling, 2012). Block nets may be positioned around the electrofished area to ensure a closed population (e.g., Peterson et al., 2005; Bertrand et al., 2006), although installation of these is labor intensive.

Electrofishing may be harmful to fish, resulting in injury or mortality through hemorrhage or spinal injury (Snyder, 2003). A wide range of factors has been associated with this including electric current type, voltage, species and body size (Dolan and Miranda, 2004; Clément and Cunjak, 2010). Registration of injury and mortality rates is necessary if the intention is to improve the electrofishing program to minimize adverse effects on the fish. An additional advantage of using block nets is that they aid in counting electrofishing-induced mortality and injury. Undetected dead or injured fish may be entrained by the river flow to later be impinged on the downstream net where they can be counted after each pass.

We evaluate the potential sources of bias when using multi-pass electrofishing for estimating population abundance and body size distribution of juvenile Atlantic salmon (*Salmo salar* L.). In particular, we examine for different size groups: (1) the dependency of abundance estimates on the number of passes used; (2) the dependency of abundance estimates on the use of block nets; and (3) electrofishing-induced mortality.

2. Material and methods

2.1. Electrofishing surveys

Five salmon-bearing rivers situated in central Norway (the rivers Homla, Ingdalselva, Levangerelva, Toåa and Vindøla; Fig. 1) were selected for electrofishing. These rivers have sympatric populations of Atlantic salmon and brown trout (*Salmo trutta* L.), but the fish communities are dominated by Atlantic salmon. Atlantic salmon within these rivers mainly smoltify in the spring at age 2–5 years, and the juvenile populations in the summer and autumn consist of individuals aged from age 0+ (year of hatching) to 4+ (the fourth year after hatching).

Electrofishing was conducted during daytime within sites that were enclosed with block nets on a total of ten occasions from August to November (2010–2015). Three of the five rivers were surveyed on more than one occasion (Table 1). When rivers were surveyed on more than one occasion, the same site was used (with the exception that the site for Homla in November 2010 was different to the other years due to operational constraints). Criteria for selecting sites were: (1) water depths that were wadeable, allowing back-pack electrofishing over the entire area; (2) channel widths and depths that were suitable for block nets to span the entire channel; (3) water conductivity that was both suitable for the use of the electrofishing gear, and typical of Norwegian rivers; and (4) a relatively similar hydromorphology among sites (with regard to water depth, current speed and riverbed substrate) to minimize the effect of differences in site-specific hydromorphology on electrofishing estimates.

The channel downstream of the electrofishing site was blocked by a fine mesh net (30 m in length, 2 m in depth, with a 5 mm mesh size) before the application of the electrofishing gear to prevent fish escape during electrofishing. The upper part (float line) of the block net was fixed above the surface of the water using sticks and the lower part of the block net was held down with large stones to ensure that the entire water column was encompassed. An additional block net was installed upstream of the site after the first electrofishing pass. An upstream block net was only installed on completion of the first round of electrofishing to ensure that a sufficient sample size had been obtained to justify continuation of the multi-pass survey: installation after this pass allowed the decline in numbers captured with successive passes to be assessed. Electrofishing was done using a TERIK FA-50 model (Terik Technology AS, www.terik.no), a Pulse Direct Current (PDC) generator model which adjusts the voltage applied to the water conductivity so as to minimize the conductivity-induced bias, while maintaining a voltage level low enough to minimize damage to the fish. Voltage varied between 700 and 1050 V, depending on the water conductivity of the site under investigation.

Electrofishing was carried out using the standard method applied in Norway of two field researchers wading upstream through the river in a zig-zag path, one of whom operated the electrofishing gear while the other assisted and took care of captured juveniles. In addition, two people continuously checked the lower block net to collect and retain impinged juveniles. After each pass, all captured juveniles were registered and classified with regard to species and status (alive or dead) and their lengths were measured. From 2013 onwards, the position of capture (whether at the electrofishing gear or in the block net) was recorded to assess the influence of block nets on the estimates of capture probability and abundance. Captured juveniles were kept in containers holding river water and were returned to the river after the electrofishing survey was completed. Repeated electrofishing passes were carried out, with the time from the start of one pass to that of the next pass being at least 30 min. Electrofishing was conducted for a larger number of passes than the traditional three-pass electrofishing approach (7–13 passes, dependent on survey; Table 1). In eight surveys, numbers of Atlantic salmon captured in the final pass were less than 2.2% of total salmon capture in all passes; in two surveys, numbers captured in the final pass were ~8-9%.

After the completion of electrofishing in each site in September 2010, the site's area (between the block nets) and hydromorphological characteristics were measured. Water depth was measured on cross-channel transects separated by 3–5 m. At the same measuring points, the bottom substrate within an iron frame (0.25 m^2) was classified and the number of potential hiding places for juveniles was calculated according to the method of Finstad et al. (2007). Water depths were shallow, with mean depths ranging from 10 to 40 cm (see Fig. 1 for surveys in 2010). All sites were dominated by pebble and cobble substrata.

2.2. Analyses

Captured juveniles showed multi-modal length distributions, largely corresponding to different age-classes (Online Supplementary Fig. 1). To enable assessment of the effect of fish size on electrofishing estimates, captured juveniles were classified into three size groups: small juveniles < 60 mm total length that mainly corresponds to young-of-the-year (fish hatched that year), medium juveniles 60–95 mm total length mainly consisting of yearlings and older parr, and large juveniles (> 95 mm) mainly correspond to the presmolt group (Elson, 1957) likely to smoltify and leave the river in the following spring. Size-at-age differed between rivers with larger specimens in the lowland Homla, Ingdalselva and Levangerelva rivers, than in the higher-gradient Toåa and Vindøla rivers.

When estimating size-specific capture probability and abundance, we used the Carle and Strub removal method (Carle and Strub, 1978) available in the R-package, FSA (Ogle, 2015). This method was chosen because it typically provides the most reliable estimates (Cowx, 1983). However, estimates from this method were similar to those from the Zippin (1958), Moran (1951) and Schnute (1983) removal methods (Online Supplementary Fig. 2), suggesting that for the data used in this study, the specific removal method will have had little effect. Estimates