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Estimating whole-lake fish catch per unit effort

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ABSTRACT

The European standard for gillnet sampling to characterize lake fish communities stratifies sampling effort (*i.e.*, number of nets) within depth strata. Nets to sample benthic habitats are randomly distributed throughout the lake within each depth strata. Pelagic nets are also stratified by depth, but are set only at the deepest point of the lake. Multiple authors have suggested that this design under-represents pelagic habitats, resulting in estimates of whole-lake CPUE and community composition which are disproportionately influenced by ecological conditions of littoral and benthic habitats. To address this issue, researchers have proposed estimating whole-lake CPUE by weighting the catch rate in each depth-compartment by the proportion of the volume of the lake contributed by the compartment. Our study aimed to assess the effectiveness of volume-weighting by applying it to fish communities sampled according to the European standard (CEN), and by a second whole-lake gillnetting protocol (VERT), which prescribes additional fishing effort in pelagic habitats. We assume that convergence between the protocols indicates that volume-weighting provides a more accurate estimate of whole-lake catch rate and community composition. Our results indicate that volume-weighting improves agreement between the protocols for whole-lake total CPUE, estimated proportion of perch and roach and the overall fish community composition. Discrepancies between the protocols remaining after volume-weighting may be because sampling under the CEN protocol overlooks horizontal variation in pelagic fish communities. Analyses based on multiple pelagic-set VERT nets identified gradients in the density and biomass of pelagic fish communities in almost half the lakes that corresponded with the depth of water at net-setting location and distance along the length of a lake. Additional CEN pelagic sampling effort allocated across water depths and distributed throughout the lake would therefore help to reconcile differences between the sampling protocols and, in combination with volume-weighting, converge on a more accurate estimate of whole-lake fish communities.

1. Introduction

Fish are regarded as effective indicators of the ecological status of aquatic ecosystems (Karr, 1981). In a healthy lake, fish typically occupy all major habitats (*i.e.*, littoral, profundal, limnetic) and a wide spectrum of trophic niches ranging from primary consumers (*i.e.*, herbivores) and detritivores through to tertiary consumers (*i.e.*, piscivores). Different fish species prefer and tolerate different physico-chemical regimes meaning that changes in fish community composition can reflect shifting ecological state (*e.g.*, Mehner et al., 2005). Fish are generally long-lived and therefore depict environmental effects integrated over several years (Harris, 1995). They also play a key role in structuring the lake ecosystem as they control zooplankton and benthic macroinvertebrate communities, which in turn regulates primary production (Carpenter et al., 1985). In addition to fisheries and lake management questions, lake fish also provide a convenient subject for research into community ecology (Boit et al., 2012), resilience theory (Ibelings et al., 2007) and ecosystem functioning (Holmlund and Hammer, 1999).

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Despite the useful information that can be gained from quantifying the composition of lake fish communities, all methods for surveying these animals in medium to large lakes carry some sort of bias. In order to use fish as an effective bioindicator or for community ecology research, a measure of the fish community must be clearly defined that acknowledges, accommodates, or accounts for these biases. Gillnetting has been widely adopted across Europe as a means of survey lake fish communities as it requires minimal infrastructure and expertise, and can be deployed throughout all major habitats of a lake. The accepted biases of gillnetting are that it tends to under-represent less-active (Backiel and Welcomme, 1980) and long, slender species such as char, pike and eels (Olin et al., 2009), over-represents the proportion of species with spines or rigid appendages (*e.g.*, perch, pikeperch; Prchalová et al., 2008), and that its size-selective (Prchalová et al., 2009), such that each mesh size most efficiently catches a particular size of fish.

For the purpose of tracking broad ecological changes in a lake through time, the influence of most gillnetting biases can be minimized by consistently surveying with the same mesh sizes and the same level of replication throughout a lake. However, comparisons *among* lakes may be affected by the way a gillnetting protocol accommodates differences in lake morphometry. Deeper lakes have a higher proportional volume of pelagic water and the heterogeneity in the distribution of fish populations throughout the lake increases with lake size and depth. Sampling protocols need to accommodate these differences in order to achieve an accurate representation of whole-lake fish communities. The distribution of sampling effort throughout the volume of a lake is particularly important when the focus of the sampling program is to determine the quantity of fish *i.e.*, biomass, abundance, community composition.

The European standard for sampling fish in lakes using multi-mesh gillnets "... provides a whole-lake assessment for species occurrence, quantitative relative fish abundance and biomass expressed as Catch Per Unit Effort (CPUE), and size structure of fish assemblages in temperate lakes" (Scope p5; Comité Européen de Normalisation, 2005; hereafter refered to as the CEN protocol). Numerous important contributions have been made to understanding factors influencing whole-lake fish communities which were based in data collected by the CEN gillnetting protocol. Mehner et al. (2005) used data collected according to the protocol to identify that fish community composition is strongly influenced by lake morphometry and primary productivity in 67 lakes across north-east Germany. Diekmann et al. (2005) extended this analysis using the same set of lakes to show that these lakes cluster into three groups represented by indicator species vendace (*Coregonus albula*), bream (*Abramis brama*) and smelt (*Osmerus eperlanus*). Brucet et al. (2013) investigated the influence of geographic and anthropogenic factors on lake fish communities using CEN gillnetting data collected in 1632 lakes across Europe. They similarly showed that lake morphometry and primary productivity shaped fish diversity, density and body size. Several fish-focused indices of biological integrity have also been developed based on, and for application with, data collected under the CEN protocol (Argillier et al., 2013; Launois et al., 2011; Lyche-Solheim et al., 2013).

Scientific contributions based on the CEN protocol are becoming increasingly common as the database of surveyed lakes increases in spatial and temporal extent. It is therefore important to understand the methodological idiosyncrasies of the protocol in order to appropriately interpret the results of research based on this method. Alexander et al. (2015) recently highlighted that characterisation of lake fish based on data collected according to the CEN protocol is strongly selective towards species in benthic habitats. Other authors have also commented on the heavy benthic emphasis of the protocol and advocated additional sampling effort in pelagic waters to better represent fish communities throughout the lake (Achleitner et al., 2012; Deceliere-Vergès and Guillard 2008; Diekmann et al., 2005; Jeppesen et al., 2006; Lauridsen et al., 2008). Mehner et al. (2005) accommodated the uneven distribution of sampling effort among habitats under the CEN protocol by weighting whole-lake CPUE based on the volumetric contributions of the littoral, benthic and pelagic habitats. They estimated the volume of these habitat-compartments by treating each lake as an ideal cone. Lake maximum depth formed the cone height and the lake surface area forming the area of the base, from which the circumference could be derived. Lauridsen et al. (2008) expanded on this approach, dividing benthic and pelagic habitats into smaller compartments based on depth strata used to allocate netting effort in the CEN protocol. They identified that estimates of whole-lake CPUE are strongly influenced by the morphometry of a lake. They also showed that the proportion of netting effort between benthic and pelagic habitats influences perceived relationships between fish communities and ecological conditions such as nutrients. The risk with applying a volume-based adjustment to CEN protocol data is that estimates of pelagic fish community come only from a single position, the deepest point of the lake, and therefore overlook spatial variability in this habitat. The CEN protocol acknowledges that horizontal variation of pelagic fishes is not adequately sampled under the protocol and, since pelagic waters constitute the vast majority of the volume of a lake, inaccurate or unrepresentative estimates of pelagic fishes will be magnified by the volume-based correction.

A second whole-lake gillnetting protocol for fish communities has been developed and extensively applied in the lakes of eastern France which also aims to provide whole-lake estimates of fish abundance, biomass and community composition (Degiorgi, 1994; Degiorgi et al., 1993a,b; 2001). This protocol prescribes gillnets that simultaneously sample from the lake surface to the lake floor. Nets are longest on the vertical axis so the protocol is hereafter referred to as the vertical netting or VERT protocol. Sampling effort under the VERT protocol is allocated among littoral and deep-water habitats. Littoral habitats (depth < 5 m) are defined according to the habitat architecture of a site (*e.g.*, macrophytes, boulders, sediment). Up to five deep-water (*i.e.*, depth > 5 m) habitat compartments are defined according to the maximum depth of the lake (see methods section for more details). Alexander et al. (2015) compared the CEN and VERT protocols for characterizing lacustrine fish communities (based on raw catch data) and suggested that the larger net area and spatial replication of pelagic nets under the VERT protocol results in a more accurate estimate of fish communities throughout an entire lake.

This paper builds on the results of Alexander et al. (2015) and aims to determine if application of a volume-based weighting of whole-lake CPUE reconciles differences in fish density, biomass and community composition between the CEN and VERT protocols. We assume that a reduction of the differences between the protocols with volume-weighting indicates convergence towards a true estimate of whole-lake catch rate and community composition (*i.e.*, towards the 'true picture' of the fish community; *sensu* Kubečka et al., 2009).

We also aim to investigate the claim by numerous researchers that the CEN protocol does not adequately represent pelagic communities by setting pelagic nets only at the deepest point of the lake. We used VERT nets distributed throughout the lake to test for the presence of spatial gradients in the pelagic fish community. The results of this analysis will guide allocation of additional CEN pelagic netting effort to best represent the whole-lake fish communities.