Ecological Indicators 77 (2017) 368–376

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Optimal gillnet sampling design for the estimation of fish community indicators in heterogeneous freshwater ecosystems

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ARTICLE INFO

Article history:
Received 10 July 2016
Received in revised form 2 January 2017
Accepted 24 February 2017

Keywords:
Ecological assessment
Fish metrics
Fish monitoring
Spatial gradients
Freshwater reservoirs

ABSTRACT

Monitoring of biota in heterogeneous ecosystems requires sampling in different habitats and across environmental gradients. The resulting multivariate community data are typically aggregated into one or several indicator values for the entire ecosystem, but the relationship between the robustness of such indicators and sampling effort, including the identification of minimum acceptable sampling designs, is not fully understood.

We address this issue for multi-mesh gillnet sampling of freshwater fish communities in deep-valley reservoirs, using data from 29 detailed annual surveys in eight reservoirs in the Czech Republic that account for the inherent longitudinal and depth gradients and the qualitatively different benthic and pelagic habitats. We evaluate the performance of eight sampling scenarios, created by variously reducing the full dataset. To this end, we use 31 fish-based, community-, size- and species-level indicators calculated separately for benthic and pelagic habitats, and fit the relationships between the indicator values based on the reduced and full sampling design using Bayesian generalized linear models.

The ability of reduced data to estimate the "true" indicator value across the entire dataset, expressed as the adjusted R^2 value of the best model for the given indicator, increased with sampling effort. However, the relationships differed between indicators: R^2 values were higher for abundance-based than for biomass-based indicators. We identified three suitable reduced sampling designs: (1) sampling the entire longitudinal profile in the epilimnion, yielding on average the highest R^2 values (0.97), (2) same as before but limited to one sampling layer closest to the surface ($R^2 = 0.91$), and (3) sampling all depth strata at the farthest points of the longitudinal gradient (*i.e.*, dam and tributary, $R^2 = 0.83$). These results demonstrate that, in order to obtain robust estimates of fish community indicators, current gillnet sampling protocols can be optimized to reduce effort and minimize unwanted fish mortality.

1. Introduction

Natural systems change under a variety of pressures, from local anthropogenic stressors to climate change, and these changes are clearly apparent in aquatic ecosystems (Jeppesen et al., 2005, 2010; Emmrich et al., 2014). One of the most sensitive aquatic biota are fish, which often represent top trophic levels integrating the changes in the entire food web (Karr, 1981; Karr et al., 1986). Therefore, many fish-based indicators were devised and used in country- (Kelly et al., 2012; Olin et al., 2013) to continental-scale (Argillier et al., 2013; Blabolil et al., 2016a) assessments of ecosystem health, which are often required by law (ANZECC, 2000; EC, 2000; CWA, 2006).

The ability of indicators to reliably convey an ecosystem state critically depends on the accuracy and precision of the underlying data, because robust and consistent datasets are needed to precisely define ecosystem state. High-quality data require sufficient sampling effort, which may be demanding in terms of labour, time and money. Many studies have thus strived to design optimal monitoring strategies (Hirzel and Guisan, 2002; MacKenzie and

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http://dx.doi.org/10.1016/j.ecolind.2017.02.036
1470-160X/

Royle, 2005; Dole-Olivier et al., 2009) and optimal management strategies (Gerber et al., 2005; Bogich et al., 2008) that are both efficient and biologically relevant. These studies usually optimize the survey design and techniques with respect to the number of samples, timing, frequency, and overall costs (Gerber et al., 2005; MacKenzie and Royle, 2005; Klečka and Boukal, 2011). However, existing approaches focus on species presence or richness (Bogich et al., 2008; Dole-Olivier et al., 2009; Hirzel and Guisan, 2002), used mainly in biodiversity assessment. However, ecosystem services such as nutrient cycling or trophic interaction strengths are driven by other system properties such as the total abundance, biomass and size distribution of keystone species including fish (Karr, 1981; Karr et al., 1986). Moreover, proportion of a given species in the community can provide important insights into ecosystem health (Blabolil et al., 2016a). New approaches towards finding optimal sampling designs for those purposes are thus needed.

Finding an optimal sampling design is easier for a given sampling technique. Gillnet sampling features prominently among methods currently used to study fish communities (Kubečka et al., 2009). Gillnet data were largely exploited in Europe recently in order to analyze the ecological status of lakes (Argillier et al., 2013), ecological potential of reservoirs (Blabolil et al., 2016a), size spectra of lake fish assemblages (Emmrich et al., 2014), and fish diversity (Brucet et al., 2013). Gillnets are popular because of their simplicity, low costs and availability of standard sampling protocols (CEN, 2005; Bonar et al., 2009). They can be deployed in a variety of lentic water habitats and provide information on species composition, abundance and age structure (CEN, 2005; Bonar et al., 2009). However, gillnets only provide relative fish abundance and biomass data (CEN, 2005), their efficiency depends on species- and size-specific fish activity (Kurkilahti et al., 2002; Prchalová et al., 2009a; Blabolil et al., 2016b) and gear saturation (Olin et al., 2004; Prchalová et al., 2010).

The European protocol describes two versions of gillnet sampling: standard sampling and inventory sampling with fewer gillnets (CEN, 2005). In both cases, depth-stratified sampling in randomly chosen localities is required (similar to the North American protocol, see Bonar et al., 2009). Even though deep habitats provide little additional information (Deceliere-Vergès et al., 2009; Prchalová et al., 2008, 2009b; Achleitner et al., 2012; Yule et al., 2013), the European sampling protocol always requires sampling the hypolimnetic layer in thermally stratified water bodies (CEN, 2005). The random site selection component of European sampling stems from the initial development of the method in relatively homogeneous environment of natural, shallow Swedish lakes without clear environmental gradients (Appelberg et al., 1995). In more heterogeneous ecosystems, random site selection requires potentially tedious prior planning with up-to-date bathymetric maps and is usually replaced by a design that covers the main axes of spatial variation.

Deep-valley reservoirs are prime, widespread example of aquatic heterogeneous ecosystems. Hydrological characteristics of reservoirs are intermediate between lakes and rivers, and include lacustrine, transitional and riverine components (Wetzel 2001). Conditions in reservoirs change along two main axes of variation: longitudinal (*i.e.*, increasing depth and decreasing productivity from the inflow to the dam part) and vertical (*i.e.*, temperature, light and oxygen gradient between the bottom and the surface; Straškraba, 2005). Moreover, benthic and pelagic habitats in reservoirs may host profoundly different fish assemblages (Prchalová et al., 2008, 2009b; Vašek et al., 2016). This complexity suggests that stratified gillnet sampling of the entire gradients should be used to get precise estimate of fish indicators. However, such coverage requires extensive sampling effort. The sampling design should be thus optimized to get robust data without excessive effort in terms of sampling locations.

Gillnet catch processing is also often time consuming. The European protocol requires that, at a minimum, following data be collected: species list, total number and weight of caught fish, biomass per unit effort (BPUE), abundance per unit effort (NPUE), and length (and/or weight) frequency distributions for all dominant species. While identification and counting of individuals can be done when fish are removed from the net, measuring and weighting is much more demanding, which makes any effort reduction attractive.

Finally, gillnets are lethal (Žydelis et al., 2013; Winfield et al., 2009) and hence not used for regular monitoring in Belgium, the Netherlands and the United Kingdom (Jan Breine, Nico Jaarsma, Graeme Peirson, personal communication). For ethical reasons and to improve animal welfare, as well as to minimize conflicts of interests with local conservation or recreational fisheries, applying the lowest required sampling effort is imperative when using lethal methods such as gillnets.

The aim of this study was to test the performance of different reduced sampling scenarios along the key gradients in heterogeneous temperate reservoirs and to identify scenarios which minimize the loss of information while substantially reducing sampling effort and reducing fish mortality by reducing the number of sampling sites. To this end, we used main overall fish assemblage indicators (total fish abundance, total and size-related biomass, and species richness) and five species-specific indicators for the most common species with different ecological niches to compare reduced sampling designs. Our results help identify cost-effective gillnets sampling designs that improve fish survival while maintaining an appropriate level of ecological scrutiny.

2. Material and methods

2.1. Dataset

We used gillnet sampling data from 29 different surveys performed between 2004 and 2014 at eight reservoirs in the Czech Republic, each sampled 1–11 times (Table 1). These reservoirs were created by flooding river valleys and share similar canyon-shaped morphologies. The morphology and external nutrient loading cause a longitudinal environmental gradient from eutrophic conditions in the tributary area to mesotrophic conditions near the dam part (Table 1). Due to the trophic status, morphology (maximum depth 20–74 m, surface area 0.6–45 km^2) and relatively long retention time, summer thermal stratification was well developed during all sampling campaigns in the 3–8 m depth range (Table 1). All the reservoirs also had passed through the initial, unstable phase of fish community succession (Kubečka, 1993). The epilimnion layer depth slightly differed between repeated sampling campaigns in the same reservoir due to interannual variation in water levels and other environmental conditions (Table 1).

2.2. Fish sampling

Sampling was performed between July and August when the reservoirs had strong thermal and oxygen stratifications. Fish communities were sampled by benthic and pelagic gillnets (hereafter BG and PG, respectively). Depth-stratified sampling, total effort based on reservoir area, and maximum sampled depth layers followed the European sampling protocol (CEN 2005). Due to the longitudinal gradient, sampling sites were not selected randomly but were allocated to sections with similar trophic characteristics and included *a priori* defined localities, at least three in each reservoir (*i.e.* dam, middle, and tributary part, Table 1).

Depth layers for BG were preset to 0–3, 3.1–6, 6.1–9, 9.1–12, 12.1–18 and >20 m; all available layers were sampled at each local-