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Evaluating the relationship between mean catch per unit effort and abundance for littoral cyprinids in small boreal shield lakes

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ABSTRACT

Catch per unit effort (CPUE) is commonly used as a relative measure of littoral fish abundance; however, few studies have examined this relationship for boreal shield lakes. We used non-linear regression to generate relationships between mark-recapture abundance estimates and mean CPUE derived from 7 years of standardized fishing using baited minnow traps for two common cyprinid species; pearl dace (*Margariscus margarita*) and fathead minnows (*Pimephales promelas*), in littoral areas of two small boreal lakes. We produced significant, positive CPUE-abundance relationships for pearl dace and fathead minnows. Pearl dace were less variable in daily CPUE during the course of the study, suggesting they may require less sampling effort than fathead minnows to precisely estimate their population size. Density estimates derived from our estimates of abundance were consistent with those from similar boreal shield lakes, providing confidence in our method to estimate abundance. Finally, we developed relationships to estimate population size from long-term monitoring data collected on these same cyprinid species using two types of small mesh trap nets. Non-linear relationships were developed between mean trap net CPUE and abundance estimates derived from minnow traps for fathead minnows, but not pearl dace. These relationships should permit population estimates from mean CPUE data collected using similar capture methods in similar lakes.

1. Introduction

Data collection to form accurate and sufficiently precise population estimates is inherently labour-intensive and can require multiple sampling of the same site for mark and recapture events. As a result, mean catch per unit effort (CPUE) has become an established metric of relative abundance for terrestrial and aquatic animals, particularly for single-event sampling programmes (Seber, 1982; Maunder, 2001; Maunder and Langley, 2004). This is especially true in freshwater systems, where mean CPUE data are often collected by single-event monitoring programmes that employ lethal sampling. Depending on what other information is collected, this may permit the estimation of population sizes and form the basis of annual harvest quotas for valuable commercial and recreational game fish species (Ontario Ministry of Natural Resources, 1991; Forage Task Group, 2011; Walleye Task Group, 2011). Further, CPUE has been used by regulators to monitor for potential changes in fish populations related to industrial activities (Gahcho Kue Project, 2010), to study effects of invasive species (Hoyle et al., 2008), human exploitation (Post et al., 2008) and anthropogenic substances (Kidd et al., 2007).

A common criticism of CPUE is that it does not provide a quantitative measure of actual fish abundance (Beverton and Holt, 1957), because it used in this way assumes strict proportionality between these two parameters (Harley et al., 2001; Maunder, 2001). However, in some cases, CPUE has been shown to be "density-invariant", whereby decreases in CPUE are not evident until fish density has been dramatically reduced (Post et al., 2002). Non-proportional relationships between CPUE and abundance, including hyperstability—where CPUE remains high while abundance drops—and hyperdepletion—where CPUE declines faster than abundance (Hilborn and Walters, 1992)—present a challenge for understanding the efficacy of CPUE as an indicator of abundance (Hubert et al., 2012). For example, commercial and recreational fishing data, which are inherently spatially biased, are prone to result in a hyperstable relationship between CPUE and abundance (Matsuishi et al., 1993; Harley et al., 2001; Gaertner and Dreyfus-Leon, 2004). Deviation from the assumption of direct proportionality may result in the over- or under-estimation of abundance using CPUE data (Harley et al., 2001; Tsuboi and Endou, 2008) and presents a serious obstacle in estimating population sizes accurately. Presently, passive sampling gear such as minnow traps and trap nets are commonly used by industry and government

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monitoring programmes to capture forage fish for environmental assessment and in long-term monitoring of aquatic systems, although no studies to date have examined how CPUE of these gear types relate to estimates of abundance.

Boreal freshwater lakes represent the most abundant lake-type globally (Schindler et al., 1996) and are affected by climate change, food web alteration and increased exploitation (Schindler and Lee, 2010). Boreal lakes are home to highly prized commercial, recreational and subsistence fish species such as lake trout (*Salvelinus namaycush*), walleye (*Sander vitreus*) and northern pike (*Esox lucius*); however, the longevity of these piscivorous fish species often makes it difficult to identify the effect of stressors on their populations. Alternatively, the short-lived nature of cyprinid species has made them model organisms for indicating effects of environmental changes on fish populations (Elser et al., 1998; Kidd et al., 2007; State of The Great Lakes, 2009: 82–88; EKATI Diamond Mine, 2012). Fisheries managers should use estimates of productivity when assessing impacts on fish communities (Minns et al., 2011), but because few agencies have the resources to initiate full-scale population studies on littoral fish communities in boreal lakes, they often rely on mean CPUE to infer changes in abundance of littoral cyprinids. Due to issues surrounding hyperstability and hyperdepletion, it has remained unknown whether cyprinid CPUE provides an accurate representation of cyprinid abundance in boreal freshwater lakes.

For a period of 7 years, we conducted an annual mark-recapture study of adult size classes of two littoral minnow species common to Canadian boreal lakes to achieve the following objectives: (1) quantify the relationships between mean CPUE and mark-recapture abundance estimates obtained from minnow traps for cyprinid species with different life-histories; (2) evaluate sampling effort and methodology to better design future monitoring programmes using minnow traps; and (3) examine the relationship between mark-recapture abundance estimates (derived from minnow traps) and mean CPUE data from a second type of trapping method (two types of trap nets) to provide estimates of population size for a long-term monitoring programme.

2. Methods

We conducted annual mark-recapture and trap net sampling of pearl dace (*Margariscus margarita*) and fathead minnows (*Pimephales promelas*) during the fall (September–October) of 1999–2005 at Lakes 260 (L260) and 442 (L442) located within the Experimental Lakes Area (ELA), northwestern Ontario, Canada (Fig. 1). Both lakes are considered oligotrophic and are similar size; L260 is 34 ha in area, with a maximum depth of 14.4 m, while L442 has an area of 16 ha, maximum depth of 17.8 m. The littoral region (≤3 m depth) of L260 is 40% of lake area and for L442 is 16%. The study lakes have similar fish communities, including lake trout as a top predator, white sucker (*Catostomus commersonii*), slimy sculpin (*Cottus cognatus*) and a number of cyprinid species such as northern red-belly dace (*Phoxinus eos*) and finescale dace (*P. neogaeus*) in addition to pearl dace and fathead minnow. From 2001 to 2003, L260 was manipulated by addition of an endocrine disrupting chemical (EDC) that subsequently resulted in a substantial decline of the fathead minnow CPUE and a moderate decline of the pearl dace mean CPUE (for details, see Palace et al., 2006, 2009; Kidd et al., 2007). L442 is a long-term reference lake at the ELA that was not altered for the duration of the study.

2.1. Mark-recapture study

Fall mark-recapture studies were designed for use with the Schnabel estimator and were comprised of 10–11 days (d) trapping periods. During these events, 30 minnow traps baited with a pasta/flour mixture were evenly set around the perimeter of the lake in the littoral zone (<3 m in depth). Minnow traps were standard Gee^{TM} traps made of square galvanized mesh (6.4 mm bar measure), but modified to have a single opening at one end. Minnow traps were collected and re-baited daily. After removal from traps, fish were placed into holding containers with lake water and transported to shore where all fish were sorted by species. The first day of trapping each year consistent of only marking fish, and subsequent days consisted of counting the number of marked and unmarked fish captured, as well as adding new marks to previously unmarked fish. Fish marking involved clipping the tip of the caudal fin using scissors (Palace et al., 2006). All previous clips and mortalities were noted and live fish were then returned to the lake. All fish were released from a single point on the lake. On the last day of mark-recapture trapping, marked fish and unmarked fish were counted and no new marks were added.

We used the Schumacher–Eschmeyer version of the Schnabel estimator to produce abundance estimates from our mark-recapture study (Schnabel, 1938; Schumacher and Eschmeyer, 1943; Ricker, 1975; Schneider, 1998). This method is based on minimizing the weighted sum-of-squares between the proportion of marked fish in a random sample and the total population using the following equation:

$$N_{\text{est}} = \frac{\sum_{d=1}^{n} C_d M_d^2}{\sum_{d=1}^{n} R_d M_d} \quad (1)$$

where:

N_{est} = estimate of population size in numbers of individual fish;
C_d = total number of fish capture on day d;
R_d = the number of recaptures (fish previously marked) caught on day d;
M_d = the number of previously marked fish available for recapture at the start of day d;
n = the total number of sampling days;
d = individual sampling day, ranging from the first (d_1) to last (d_n).

As this method uses a sample to estimate population size, there is uncertainty or error associated with the population estimate, which we calculated using the following equations:

$$s^2 = \frac{\sum_{d=1}^{n} (R_d^2/C_d) - \left[\left(\sum_{d=1}^{n} R_d M_d\right)^2 / \left(\sum_{d=1}^{n} C_d M_d^2\right) \right]}{m-1} \quad (2)$$

where:

s^2 = sample variance;
m = number of sampling days on which fish were captured.

$$\text{SE}_{N_{\text{est}}} = \sqrt{N_{\text{est}}^2 \times \left[\frac{N_{\text{est}} s^2}{\sum_{d=1}^{n} R_d M_d} \right]} \quad (3)$$

where:

$\text{SE}_{N_{\text{est}}}$ = the standard error of the population estimate (N_{est}).

The Schnabel method assumes that (1) the population is closed (births, deaths and migration do not occur); (2) all fish are equally catchable; and (3) marked fish are not misidentified (Schnabel, 1938; Schumacher and Eschmeyer, 1943; Ricker, 1975). Both study lakes have shallow inflow and outflow streams which often run dry by mid-summer. We assume that migration among these lakes is negligible, and our systems were closed during the study (M. Docker, unpublished data). We believe that our study methods met the second and third assumptions of the Schnabel method. Traps