Notes
Efficiency of Sampling Sunfishes Using Snorkeling in Clear, Warm-Water Streams of the South-Central United States

Robert Mollenhauer, Shannon K. Brewer*

R. Mollenhauer
Oklahoma Cooperative Fish and Wildlife Research Unit, Oklahoma State University, Stillwater, Oklahoma 74078

S.K. Brewer
U.S. Geological Survey, Oklahoma Cooperative Fish and Wildlife Research Unit, Oklahoma State University, Stillwater, Oklahoma 74078

Abstract

The continued evaluation of fish-sampling gears and methods is essential to identify their applicability across environmental conditions and among species. Although limited by visibility, snorkeling has potential advantages relative to other fish-sampling gears in wadeable streams (e.g., minimally intrusive, cost effective, and appropriate in deeper areas). Clear water is common to warm-water streams; however, the use of snorkeling for monitoring stream-fish populations has largely focused on cold-water systems. To assess relative snorkeling efficiency in warm-water streams, we compared standardized single-pass snorkel counts to tow-barge electrofishing abundance estimates for six sunfishes (Centrarchidae) in the Ozark Highlands ecoregion of northwest Oklahoma and southwest Missouri under relatively similar environmental conditions (i.e., clear water, cobble substrates, low-flow conditions). Snorkeling efficiency was variable among sunfishes and consistently low for species with cryptic traits and habitat use. We also did not detect cryptic sunfishes (i.e., a single individual was not encountered) using snorkeling at multiple stream reaches where estimated abundance was > 50 within a 0.5- to 1.0-km stream reach. Our findings indicate that snorkeling has applications for monitoring sunfish populations and assemblages when using an abundance estimator or accounting for imperfect detection; however, it is inappropriate for estimating population size of cryptic sunfishes. We encourage continued research into the applicability of snorkeling to estimate warm-water stream fish abundance.

Keywords: snorkeling; sampling efficiency; sampling; Lepomis; Ambloplites

Introduction

All fish-sampling gears are imperfect and biased in some way. Stream-fish capture probability (i.e., the estimated proportion of individuals captured) is variable across sampling conditions and among both gear types and species (Peterson and Paukert 2009; Gwinn et al. 2016). Standardizing sampling gears and methods (Bonar et al. 2009a, 2015), though important aspects of sound stream-fish monitoring, does not alleviate the inferential issues associated with variable capture probability (Peterson et al. 2004; Price and Peterson 2010; Mollenhauer et al. 2017). Thus, the continued evaluation of biases and limitations of stream-fish sampling methods is
essential for ecological advancements and well-informed conservation and management decisions. Preliminary evaluations are particularly important for fish-sampling gears with a paucity of information about potential applications (e.g., poorly evaluated species or systems). For example, initial assessments can prioritize future research directions and identify inappropriate gear types (e.g., consistently low capture probability).

Backpack and tow-barge electrofishing, along with seining, are the most common sampling methods for estimating fish abundance in wadeable streams (Rabeni et al. 2009); however, single-pass snorkel counts are an option given adequate visibility (Dunham et al. 2009; Thurow et al. 2012). Snorkeling is both minimally intrusive and cost effective (e.g., gear requirements are typically only a mask, snorkel, and wetsuit). Snorkeling is also less limited by water depth than seining and electrofishing, thus making it more applicable for sampling deeper pools.

Although clear water is often more strongly associated with cold-water streams, adequate visibility for fish snorkel counts is also common in warm-water systems. For example, many streams of the south-central United States have substantial groundwater influence and excellent underwater visibility during dry weather periods (Nigh and Schroeder 2002). However, the applicability of snorkeling to estimate stream-fish abundance in warm-water streams has received relatively little attention by researchers relative to cold-water systems (but see Dauwalter et al. 2007; Jordan et al. 2008; Brewer and Ellersieck 2011; Weaver et al. 2014; Hain et al. 2016). For example, snorkeling was among the gear choices discussed for cold-water streams, but not warm-water streams, in a recent American Fisheries Society text (Bonar et al. 2009b) outlining standard fish-sampling gears and methods. Our objective was to examine the applicability of snorkeling for monitoring sunfish (Centrarchidae) populations in wadeable warm-water streams on the basis of a relative efficiency (i.e., a point count relative to an absolute abundance estimate). We differentiated efficiency from capture probability as the former being an observed proportion and the latter a modeled estimate. The sunfishes of interest in our study were Bluegill *Lepomis macrochirus*, Green Sunfish *Lepomis cyanellus*, Longear Sunfish *Lepomis megalotis*, Redear Sunfish *Lepomis microlophus*, Rock Bass *Ambloplites rupestris*, and Warmouth *Lepomis gulosus*.

**Study area**

We sampled sunfish populations using both snorkeling and tow-barge electrofishing in 20 stream reaches in the Ozark Highlands ecoregion of northwest Oklahoma and southwest Missouri from summer to early autumn 2014–2015 (Figure 1). The Ozark Highlands are characterized by cherty–limestone lithology and oak–hickory forests, with valleys primarily converted to pasture (Woods et al. 2005). All reaches were wadeable (i.e., most habitat was < 1 m deep; Rabeni et al. 2009) and comprised three to five riffle-run-pool sequences 0.5–1 km in length to characterize in-stream habitat. We conducted all sampling under good visibility (horizontal underwater water clarity ≥ 3.0 m) and relatively low flows (0.09–4.10 m³/s). Substrate was primarily cobble across our reaches.

**Methods**

We performed standardized single-pass snorkel counts (Dunham et al. 2009) before tow-barge electrofishing using two to three trained crew members. We installed two sets of block-off nets at both the upstream and downstream end of each reach to ensure a closed system following Peterson et al. (2004). Three snorkelers sampled most reaches, but we used only two when wetted channel width was < 10 m (i.e., a third “lane” was not available in the reach; see below). We slowly sneaked stream areas ≥ 0.2-m deep in an upstream direction, while avoiding sudden movements and carefully inspecting areas of structure (e.g., under logs and between boulders). Each snorkler maintained a designated longitudinal lane and remained lateral to other crew members, while communicating using underwater hand signals to minimize double counting. When snorkelers either passed or were passed by sunfishes ≥ 50-mm total length (TL), they identified them to species and recorded them on an underwater wrist cuff. Our size restriction excluded most age-0 fishes not recruited to electrofishing (McClenond and Rabeni 1986; personal observations). We used fish silhouettes and rocks of known sizes to confirm the ability of crew to recognize fish-size cutoffs underwater (Dunham et al. 2009).

Approximately 24 h after the snorkel counts, we performed standardized two-pass removal electrofishing (Rabeni et al. 2009) using a tow barge (Midwest Lake Management, Polo, Missouri). The electrofishing crew comprised three people: one tow-barge operator armed with a hand net and two persons equipped with dip nets, each operating one of the anodes. We electrofished stream areas ≥ 0.2-m deep in an upstream direction with a zigzag pattern, while thoroughly sampling areas with structure. We used pulsed direct current, 60 Hz, and a 25% duty cycle for electrofishing. We adjusted voltage to a target power (W) to standardize the electrical field across levels of ambient water conductivity, while minimizing electrofishing-induced injuries (Miranda 2009). We measured sunfishes ≥ 50-mm TL and identified to species.

We estimated sunfish electrofishing capture probabilities (i.e., estimated number of individuals captured) using the model described by Mollenhauer et al. (2017) to calculate sunfish abundance estimates. Briefly, Mollenhauer et al. (2017) used a series of mark–recaptures across a range of sampling conditions and fish sizes (i.e., gear calibration; Peterson and Paukert 2009) to develop a multispecies electrofishing capture probability model, where a cross-validation indicated good model performance. We calculated sunfish abundance estimates for fish ≥ 50 mm TL as \( N = c/Q \) (Thompson and Seber 1994; Peterson and Paukert 2009), where \( N \) is the species-specific abundance estimate for each stream reach, \( c \) is...
electrofishing count, and \( \hat{q} \) is estimated capture probability approximated from the logit scale to values from 0 to 1 (Jørgensen and Pedersen 1998). Electrofishing counts are provided as supplemental material (Table S2, Supplemental Material).

We compared relative snorkeling efficiency among stream fishes using the snorkel count at each reach divided by the electrofishing abundance estimate. We calculated weighted means and standard deviations using the R package Hmisc (Harrell 2018) to summarize snorkeling efficiencies. We used the electrofishing abundance estimate as the sample size for the weighted statistics, where species-reach observations with counts of 0 (thus, we did not include abundance estimates of 0) were not included. We constrained snorkeling efficiency to 1 for the weighted summary statistics when snorkel counts exceeded electrofishing estimates (i.e., we used the electrofishing estimate for the snorkel count).

**Figure 1.** Twenty stream reaches of the Ozark Highlands ecoregion of northwest Oklahoma and southwest Missouri. We sampled six sunfish populations (Bluegill *Lepomis macrochirus*, Green Sunfish *Lepomis cyanellus*, Longear Sunfish *Lepomis megalotis*, Redear Sunfish *Lepomis microlophus*, Rock Bass *Ambloplites rupestris*, and Warmouth *Lepomis gulosus*) from summer to early autumn 2014–2015 using both snorkeling and two-barge electrofishing. We defined stream reaches as three to five riffle-run-pool sequences 0.5–1 km in length to characterize in-stream habitat.
Table 1. Relative snorkeling efficiency and weighted mean and SD for six sunfishes (Bluegill Lepomis macrochirus, Green Sunfish Lepomis cyanellus, Longear Sunfish Lepomis megalotis, Redear Sunfish Lepomis microlophus, Rock Bass Amblopterus rupestris, and Warmouth Lepomis gulosus) at 20 stream reaches in the Ozarks Highland ecoregion of northeast Oklahoma and southwest Missouri sampled from summer to early autumn 2014–2015 (Figure 1). We calculated snorkeling efficiency as the snorkel count (S) divided by the two-pass tow-barge electrofishing abundance estimate (E). We defined stream reaches as three to five riffle-run-pool complexes to characterize in-stream habitat. We derived electrofishing estimates using the multispecies capture probability model described by Mollenhauer et al. (2017) and used them as the sample size for the weighted means and standard deviations. We calculated the weighted summary statistics using the package Hmisc (Harrell 2018) in the statistical software R (R Core Team 2018). NA indicates reaches that were not included in the calculations because electrofishing counts were 0. Electrofishing counts and relative uncertainty for the abundance estimates are provided in Table S1.

| Stream reach         | Longear Sunfish efficiency (S/E) | Bluegill efficiency (S/E) | Redear Sunfish efficiency (S/E) | Rock Bass efficiency (S/E) | Warmouth efficiency (S/E) |
|----------------------|----------------------------------|---------------------------|---------------------------------|---------------------------|--------------------------|
| Baron Fork           | 0.36 (182/509)                   | NA (0/0)                  | NA (0/0)                        | 0.03 (3/107)              | 0.05 (1/22)               |
| Big Sugar Creek      | 0.67 (819/1,228)                 | 1.00 (130/38)*            | 0.89 (17/19)                    | 0.09 (14/154)             | 0.35 (44/125)            |
| Buffalo Creek        | 0.26 (121/466)                   | 0.14 (25/177)             | 0.00 (0/2)                      | 0.01 (1/68)               | 0.01 (3/277)             |
| Buffalo Creek2       | 0.55 (374/678)                   | 0.62 (149/239)            | NA (1/0)                        | 0.11 (11/99)              | 0.02 (5/232)             |
| Buffalo Creek3       | 0.30 (26/86)                     | 0.34 (30/88)              | NA (0/0)                        | 0.01 (1/77)               | 0.02 (7/401)             |
| Buffalo Creek4       | 0.39 (231/593)                   | 0.35 (125/361)            | 0.36 (6/17)                     | 0.15 (7/48)               | 0.03 (7/203)             |
| Butler Creek         | 0.78 (597/764)                   | 0.60 (207/344)            | 0.10 (1/10)                     | 0.03 (6/204)              | 0.03 (15/522)            |
| Caney Creek          | 0.40 (424/1,063)                 | 0.37 (140/376)            | 0.00 (0/6)                      | 0.13 (1/18)               | 0.04 (11/313)            |
| Evansville Creek     | 0.39 (344/890)                   | 0.10 (27/27)              | NA (0/0)                        | 0.08 (7/83)               | 0.02 (2/123)             |
| Evansville Creek2    | 1.00 (500/408)*                  | 0.81 (181/17)*            | NA (0/0)                        | 0.75 (18/24)              | 0.02 (2/125)             |
| Fivemile Creek       | 1.00 (264/257)*                  | 0.55 (192/352)            | 0.00 (0/4)                      | 0.04 (4/97)               | 0.01 (3/235)             |
| Flint Creek          | 0.25 (686/1,952)                 | 0.40 (4/10)               | 0.67 (2/3)                      | 0.18 (184/1,028)          | 0.02 (1/47)              |
| Fourteenmile Creek1  | 0.20 (536/2,678)                 | 0.35 (83/240)             | NA (0/0)                        | 0.01 (1/1068)             | 0.04 (22/518)            |
| Fourteenmile Creek2  | 0.14 (142/1,024)                 | 0.07 (4/54)               | 0.00 (0/4)                      | 1.00 (17/13)*             | 0.01 (5/382)             |
| Saline Creek         | 0.40 (216/540)                   | 0.28 (16/57)              | NA (0/0)                        | 0.04 (23/532)             | 0.00 (0/77)              |
| Spavinaw Creek       | 0.76 (278/365)                   | 0.22 (16/72)              | NA (0/0)                        | 0.14 (114/832)            | 0.00 (0/89)              |
| Spavinaw Creek2      | 0.27 (153/561)                   | 0.22 (603/2,687)          | 0.12 (143/1,161)                | 0.00 (0/136)              | 0.00 (0/222)             |
| Spavinaw Creek3      | 0.53 (127/241)                   | 0.30 (54/181)             | 0.00 (0/6)                      | 0.04 (9/237)              | 0.00 (0/73)              |
| Spring Creek1        | NA (0/0)                         | NA (0/0)                  | NA (0/0)                        | 0.25 (53/208)             | 0.06 (1/18)              |
| Spring Creek2        | NA (0/0)                         | 0.00 (0/8)                | NA (0/0)                        | 0.03 (11/370)             | 0.13 (4/31)              |
| All (weighted mean ± SD) | 0.41 ± 0.22                     | 0.32 ± 0.16               | 0.14 ± 0.11                     | 0.11 ± 0.10               | 0.03 ± 0.06              |

* We used the electrofishing estimate for the snorkel count in the weighted mean and SD calculation to constrain efficiency at 1.00.

Results and Discussion

Relative snorkeling efficiency (reported as weighted mean ± SD) was variable among species-reach observations (Table 1). Snorkeling efficiency ranged from 0.00 to 1.00 (0.28 ± 0.23; n = 95 species-reach observations) and was consistently < 0.10 for Rock Bass, Green Sunfish, and Warmouth. With the exception of Longear Sunfish, each species had at least one false absence using snorkeling (i.e., efficiency of 0 at a reach). Mean snorkeling efficiency was highest and most variable for Longear Sunfish (0.41 ± 0.22; n = 18 reaches) and Bluegill (0.32 ± 0.16; n = 18 reaches; one false absence). Mean snorkeling efficiency was lower and similar for Redear Sunfish (0.14 ± 0.11; n = 10 reaches; five false absences) and Rock Bass (0.11 ± 0.10; n = 20 reaches; one false absence). Estimated abundance for Redear Sunfish was almost exclusively < 20, and mean snorkeling efficiency was largely based on one stream reach located near an impoundment with disproportionately higher estimated abundance (Spavinaw Creek2; n > 1,000). Mean snorkeling efficiency was lowest and least variable for Green Sunfish (0.03 ± 0.06; n = 20 reaches; four false absences) and Warmouth (0.03 ± 0.03; n = 9 stream reaches; six false absences). Snorkel counts exceeded electrofishing estimates for five observations (Bluegill and Longear Sunfish: 2, Redear Sunfish and Rock Bass: 1). We encountered a species using snorkeling, but not electrofishing, at only one stream reach (Redear Sunfish at Buffalo Creek2; n = 1 individual).

The relatively higher and lower snorkeling efficiencies among sunfishes can be related to species traits (e.g., behavior and coloration) and habitat use. Both Longear Sunfish (Witt and Marzolf 1954; Bietz 1981) and Bluegill (Colgan et al. 1979; Dugatkin and Wilson 1992) are gregarious fishes with bright coloration often observed outside of cover, which would promote higher snorkeling efficiency (Dunham et al. 2009; Thurow et al. 2012). Conversely, sunfishes with lower snorkeling efficiency exhibited cryptic traits and habitat use. Both Green Sunfish (Werner and Hall 1977; Stuber et al. 1982) and Warmouth (McMahon et al. 1984) tend to occupy shallow, heavily vegetated areas and have cryptic coloration. Rock Bass also tend to occupy dense in-stream cover and have cryptic coloration (Casterlin and Reynolds 1979; Probst et al. 1984; Grossman et al. 1995). We also commonly observed Rock Bass using interstitial spaces and displaying skittish behavior. Other researchers have associated cryptic traits and habitat use to lower stream-fish snorkeling efficiency and capture probability (e.g., Bozek and Rahel 1991; Korman et al. 2010; Macnaughton et al. 2014).

False absences among sunfishes when using a single snorkel pass were associated with both lower fish abundance and cryptic traits. We detected a species
using snorkeling on only 2 of 10 species-reach observations when estimated abundance was < 10 (Redear Sunfish at Flint Creek and Rock Bass at Caney Creek; Table 1). However, all false absences for Green Sunfish and Rock Bass and four of six false absences for Warmouth occurred at reaches with estimated abundances > 50. McManamay et al. (2014) also observed relationships between single-pass snorkeling detection and both densities and cryptic traits for warm-water stream fishes.

We did not identify any obvious trends in snorkeling efficiency associated with water clarity and flow conditions across the ranges encountered during our sampling. For example, snorkeling efficiency between the reach sampled under the highest flows (Big Sugar Creek; 4.10 m³/s) and the reach sampled under the lowest flows (Evansville Creek2; 0.09 m³/s) was similar across sunfishes. Additionally, snorkeling efficiency was also similar at reaches sampled under both higher visibility (e.g., Flint Creek; horizontal water clarity of 5 m) and lower visibility (Fourteenmile Creek; horizontal water clarity of 3 m). However, we recognize that numerous interacting factors contribute to variation in sampling efficiency (thus, also underlying capture probability). In addition to visibility, in-stream structure (Mullner et al. 1998; Wildman and Neuman 2003), water depth (Schill and Griffith 1984; Brewer and Ellersieck 2011), underlying lithology (Ensign et al. 1995; Albanese et al. 2011), and fish densities (Hillman et al. 1992; Dunham et al. 2009) also can contribute to variable snorkeling capture probability.

Given adequate data (e.g., sample size and variation in sampling conditions), hierarchical modeling can be used to estimate capture probability and abundance and species detection probabilities among species and across sites. Multi-species electrofishing capture probability models have been developed for warm-water streams (e.g., Price and Peterson 2010; Mollenhauer et al. 2017); however, common abundance estimators are not well suited for stream-fish snorkeling applications. For example, removal estimators are generally not feasible for snorkeling because physical capture of fishes is difficult (but see Dorazio et al. 2005; Jordan et al. 2008), and a secondary method is typically required to mark individuals for mark–recapture estimation (e.g., Brewer and Ellersieck 2011). Repeated counts (e.g., Royle 2004) and repeated sighting approaches (e.g., double observer; Royle et al. 2004; Koneff et al. 2008) can be used with abundance estimators that do not require physical capture; however, evaluations of their feasibility for stream-fish snorkeling has been extremely limited (but see Webster et al. 2008). Similarly, occupancy modeling (MacKenzie et al. 2006) could be used to account for imperfect snorkeling detection when assessing stream-fish species occurrence (e.g., Hagler et al. 2011; McManamay et al. 2013; Fraley et al. 2017). Here, our objective was not to quantify or explicitly identify sources of variability related to snorkeling capture probability or detection, but rather to provide a preliminary assessment of snorkeling applications to monitor stream-dwelling sunfish populations on the basis of a relatively small number of stream reaches.

The electrofishing abundance estimates provided a useful benchmark to compare the snorkel counts; however, there are always caveats associated with modeled data and their applications. For example, relative uncertainty around the abundance estimates varied (i.e., the point estimate was more reliable at some stream reaches than at others; Table S1, Supplemental Material). Thus, in some instances relative snorkeling efficiency may have been affected by a less accurate electrofishing estimate (see Mollenhauer et al. 2017 for a detailed discussion of model performance and limitations). Nevertheless, we feel that the reasonable level of uncertainty around the vast majority of the abundance estimates and the clear trends in snorkeling efficiency among sunfishes suggest that perfect knowledge of reach-to-reach abundance (impossible to achieve) would not change our major findings.

**Management implications**

Our findings indicated that snorkeling is applicable for monitoring sunfishes in warm-water streams using single-pass snorkel counts given variable capture probability and species detection are considered. Relying solely on standardized gears and methods when comparing abundances and community metrics (e.g., species diversity and richness) among sites can lead to misinterpreted ecological relationships and misinformed conservation and management decisions. The lower efficiency for Green Sunfish, Rock Bass, and Warmouth suggests that snorkeling is inappropriate for estimating population size for cryptic sunfishes even when using an abundance estimator. The consistently low efficiency associated with sampling these species would likely result in difficulty meeting model assumptions or levels of uncertainty that would make the population estimates uninformative. The detection of Redear Sunfish at a low-density reach using snorkeling, but not electrofishing, highlights the potential value of snorkeling as a secondary gear to establish the occurrence of rarer warm-water stream fishes.

Although snorkeling is typically most often associated with cold-water stream-fish monitoring, other recent studies have also examined its applicability in clear, warm-water streams. For example, Brewer and Ellersieck (2011) evaluated snorkeling capture probability of age-0 Smallmouth Bass *Micropterus dolomieu* in Ozark Highland streams. Hain et al. (2016) compared snorkel counts with mark–recapture estimates for the stream-dwelling *O‘opu nākea Awaous guamensis* in Hawaii. Stream-fish scientists likely underappreciate the potential of snorkeling as a noninvasive sampling method to monitor warm-water assemblages, and widespread applicability across stream fishes and systems remains relatively unexplored. Identifying limitations (e.g., consistently low capture probability) and providing insight into potential bias (e.g., relationships with species traits and habitat use or prevailing environmental conditions) are important aspects of fish-sampling gear evaluations to prioritize future research directions. We encourage continued...
research into the applicability of snorkeling to estimate warm-water stream-fish abundance.

Supplemental Material

Please note: The Journal of Fish and Wildlife Management is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

**Table S1.** Two-pass tow-barge electrofishing abundance estimates and associated 95% confidence intervals (CI) for six sunfishes (Bluegill *Lepomis macrochirus*, Green Sunfish *Lepomis cyanellus*, Longear Sunfish *Lepomis megalotis*, Redear Sunfish *Lepomis microlophus*, Rock Bass *Ambloplites rupestris*, and Warmouth *Lepomis gulosus*) at 20 stream reaches 0.5–1 km in length in the Ozarks Highland ecoregion of northeast Oklahoma and southwest Missouri sampled from summer to early autumn 2014–2015.

Found at DOI: [https://doi.org/10.3996/032018-JFWM-027.S1](https://doi.org/10.3996/032018-JFWM-027.S1) (16 KB DOCK).

**Table S2.** Counts from two-pass electrofishing for six sunfishes (Bluegill *Lepomis macrochirus*, Green Sunfish *Lepomis cyanellus*, Longear Sunfish *Lepomis megalotis*, Redear Sunfish *Lepomis microlophus*, Rock Bass *Ambloplites rupestris*, and Warmouth *Lepomis gulosus*) at 20 stream reaches 0.5–1 km in length in the Ozarks Highland ecoregion of northeast Oklahoma and southwest Missouri sampled from summer to early autumn 2014–2015.

Found at DOI: [https://doi.org/10.3996/032018-JFWM-027.S2](https://doi.org/10.3996/032018-JFWM-027.S2) (15 KB DOCK).

**Reference S1.** McMahon TE, Gebhart G, Maughan OE, Nelson PC. 1984. Habitat suitability index models and instream flow suitability curves: Warmouth (No. 82/10.67). U.S. Fish and Wildlife Service. 31:1040–1051.

Found at DOI: [https://doi.org/10.3996/032018-JFWM-027.S1](https://doi.org/10.3996/032018-JFWM-027.S1) (1.01 MB PDF).

**Reference S2.** Stuber RJ, Gebhart G, Maughan OE. 1982. Habitat suitability index models: Green Sunfish. U.S. Fish and Wildlife Service FW/S/OS:82/10.15.

Found at DOI: [https://doi.org/10.3996/032018-JFWM-027.S2](https://doi.org/10.3996/032018-JFWM-027.S2) (1.13 MB PDF).

Acknowledgments

This research is a contribution of the Oklahoma Cooperative Fish and Wildlife Research Unit (U.S. Geological Survey, Oklahoma Department of Wildlife Conservation, Oklahoma State University, and Wildlife Management Institute cooperating). Funding was provided by the Oklahoma Department of Wildlife Conservation (F13AF00192). This research was conducted under the auspices of the Oklahoma State University Animal Care and Use Committee (ACUP AG-14-9). We thank Trevor Mattera, Jake Holliday, Emily Gardner, Steven Maichak, Becky Long, Joshua Mouser, and biologists of the Oklahoma Department of Wildlife Conservation for technical assistance. We also thank the Ozark Plateau National Wildlife Refuge for providing occasional lodging. Last, we thank the Associate Editor and two anonymous reviewers for comments and suggests that greatly improved the quality of this manuscript.

Any use of trade, product, website, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Albanese B, Owens KA, Weiler DA, Pruitt W. 2011. Estimating occupancy of rare fishes using visual surveys, with a comparison to backpack electrofishing. Southeastern Naturalist 10:423–442.

Bietz BF. 1981. Habitat availability, social attraction and nest distribution patterns in Longear Sunfish (*Lepomis megalotis peltastes*). Environmental Biology of Fishes 6:193–200.

Bonar SA, Contreras-Balderas S, Iles AC. 2009a. An introduction to standardized sampling. Pages 1–13 in Bonar SA, Hubert WA, Willis DW, editors. Standard methods for sampling North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Bonar SA, Hubert WA, Willis DW, editors. 2009b. Standard methods for sampling North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Bonar SA, Mercado-Silva N, Rahr M, Torrey YT, Cate A. 2015. A simple web-based tool to compare freshwater fish data collected using AFS standard methods. Fisheries 40:580–589.

Bozek MA, Rahel FJ. 1991. Capture, marking, and enumeration of juvenile Bull Trout and Cutthroat Trout in small, low-conductivity streams. North American Journal of Fisheries Management 15:563–568.

Brewer SK, Ellersieck MR. 2011. Evaluating two observational sampling techniques for determining the distribution and detection probability of age-0 Smallmouth Bass in clear, warmwater streams. North American Journal of Fisheries Management 31:894–904.

Casterlin ME, Reynolds WW. 1979. Agonistic displays in the Rock Bass, *Ambloplites rupestris*. Hydrobiologia 65:19–21.

Colgan PW, Nowell WA, Gross MR, Grant JWA. 1979. Aggressive habitation and rim circling in the social organization of bluegill sunfish (*Lepomis macrochirus*). Environmental Biology of Fishes 4:29–36.

Dauwalter DC, Splinter DK, Fisher WL, Marston RA. 2007. Geomorphology and stream habitat relationships with Smallmouth Bass (*Micropterus dolomieu*) abundance at multiple spatial scales in eastern Oklahoma. Canadian Journal of Fisheries and Aquatic Sciences 64:1116–1129.

Dorazio RM, Jelks HL, Jordan F. 2005. Improving removal-based estimates of abundance by sampling a popu-
Sampling Sunfishes via Snorkeling in Warm-Water Streams

R. Mollenhauer and S.K. Brewer

Grossman GD, Ratajczak RE, Crawford MK. 1995. Do Rock Fraley KM, Falke JA, McPhee MV, Prakash A. 2017. Ensign WE, Angermeier PL, Dolloff CA. 1995. Use of line Dunham JB, Rosenberger AE, Thurow RF, Dolloff CA, Jørgensen E, Pedersen AR. 1998. How to obtain those Jordan F, Jelks HL, Bortone SA, Dorazio RM. 2008. Comparison of visual survey and seining methods for estimating abundance of an endangered, benthic stream fish. Environmental Biology of Fishes 81:313–319. Jørgensen E, Pedersen AR. 1998. How to obtain those nasty standard errors from transformed data—and why they should not be used. Faculty of Agricultural Sciences, Aarhus University, Internal Report 7:1–20. Koneff MD, Royle JA, Otto MC, Wortham JS, Bidwell JK. 2008. A double-observer method to estimate detection rate during aerial waterfowl surveys. Journal of Wildlife Management 72:1641–1649. Korman JK, Decker AS, Mossop B, Hagen J. 2010. Comparison of electrofishing and snorkeling mark–recapture estimation of detection probability and abundance of juvenile steelhead in a medium-sized river. North American Journal of Fisheries Management 30: 1280–130. MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Bailey LL, Hines JE. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. San Diego, California: Elsevier. Macnaughton CJ, Harvey-Lavoie S, Senay C, Lanthier G, Bourque G, Legendre P, Bosclair D. 2014. A comparison of electrofishing and visual surveying methods for estimating fish community structure in temperate rivers. River Research and Applications 31:1040–1051. McClendon D, Rabeni CF. 1986. Sampling stream centrarchids: comparing electrofishing and underwater observation. Proceedings of the Annual Conference of Southeastern Association of Fisheries and Wildlife Agencies 40:92–101. McMahon TE, Gebhart G, Maughan OE, Nelson PC. 1984. Habitat suitability index models and instream flow suitability curves: Warmouth (No. 82/10.67), U.S. Fish and Wildlife Service.31:1040–1051 (see Supplemental Material, Reference S1). McManamay RA, Orth DJ, Jager HI. 2014. Accounting for variation in species detection in fish community monitoring. Fisheries Management and Ecology 21:96–112. Miranda LE. 2009. Standardizing electrofishing power for boat electrofishing. Pages 223–230 in Bonar SA, Hubert WA, Willis DW, editors. Standard methods for sampling North American freshwater fishes. Bethesda, Maryland: American Fisheries Society. Mollenhauer R, Mouser J, Brewer SK. 2017. Sampling the stream landscape: improving the applicability of an ecoregion-level capture probability model for stream fishes. Canadian Journal of Fisheries and Aquatic Sciences. 75:1614–1625. Mullner SA, Hubert WA, Wesche TA. 1998. Snorkeling as an alternative to depletion electrofishing for estimating abundance and length-class frequencies of trout in small streams. North American Journal of Fisheries Management 18:947–953. Nigh TA, Schroeder WA. 2002. Atlas of Missouri ecoregions. Jefferson City: Missouri Department of Conservation. Available: https://www.nrc.gov/docs/ML0923/ML092360302.pdf (July 2018). Oehlert GW. 1992. A note on the delta method. American Statistician 46:27–29. Reference R1. Peterson JT, Thurow RF, Guzevich JW. 2004. An evaluation of multipass electrofishing for estimating the abundance of stream-dwelling salmonids. Transactions of the American Fisheries Society 133:462–475.
Peterson JT, Paukert CP. 2009. Converting nonstandard fish sampling data to standardized data. Pages 195–215 in Bonar SA, Hubert WA, Willis DW, editors. Standard methods for sampling North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Price AL, Peterson JT. 2010. Estimation and modeling of electrofishing capture efficiency for fishes in wadeable warmwater streams. North American Journal of Fisheries Management 30:481–498.

Probst WE, Rabeni CF, Covington WG, Marteney RE. 1984. Resource use by stream-dwelling Rock Bass and Smallmouth Bass. Transactions of the American Fisheries Society 113:283–294.

R Core Team. 2018. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. ISBN 3-900051-07-0. Available: http://www.R-project.org/ (May 2018).

Rabeni CF, Lyons J, Mercado-Silva N, Peterson JT. 2009. Warmwater fish in wadeable streams. Pages 43–58 in Bonar SA, Hubert WA, Willis DW, editors. Standard methods for sampling North American freshwater fishes. Bethesda, Maryland: American Fisheries Society.

Royle JA. 2004. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60:108–115.

Royle JA, Dawson DD, Bates S. 2004. Modeling abundance effects in distance sampling. Ecology 85:1591–1597.

Schill DJ, Griffith JS. 1984. Use of underwater observations to estimate Cutthroat Trout abundance in the Yellowstone River. North American Journal of Fisheries Management 48:479–487.

Stuber RJ, Gebhart G, Maughan OE. 1982. Habitat suitability index models: Green Sunfish. U.S. Fish and Wildlife Service FWS/OBS:82/10.15 (see Supplemental Material, Reference S2).

Thompson SK, Seber GAF. 1994. Detectibility in conventional and adaptive sampling. Biometrics 50:712–724.

Thurow RF, Dolloff CA, Marsden JE. 2012. Visual observation of fishes and aquatic habitat. Pages 781–817 in Zale AV, Parrish DL, Sutton TM, editors. Fisheries techniques. 3rd edition. Bethesda, Maryland: American Fisheries Society.

Weaver DM, Kwak TJ, Pollock KH. 2014. Sampling characteristics and calibration of snorkel counts to estimate stream fish populations. North American Journal of Fisheries Management 34:1159–1166.

Webster RA, Pollock KH, Ghosh SK, Hankin DG. 2008. Bayesian spatial modeling of data from unit-count surveys of fish in streams. Transactions of the American Fisheries Society 137:438–453.

Werner EE, Hall DJ. 1977. Competition and habitat shift in two sunfishes (Centrarchidae). Ecology 58:869–876.

Wildman TL, Neumann RM. 2003. Comparison of snorkeling and electrofishing for estimating abundance and size structure of Brook Trout and Brown Trout in two southern New England streams. Fisheries Research 60:131–139.

Witt A, Marzolf RC. 1954. Spawning and behavior of the Longear Sunfish, Lepomis megalotis megalotis. Copeia 1954:188–190.

Woods AJ, Omernik JM, Butler DR, Ford JG, Henley JE, Hoagland BW, Arndt DS, Morgan BC. 2005. Ecoregions of Oklahoma. Reston, Virginia: U.S. Geological Survey. Available: ftp://newftp.epa.gov/EPADataCommons/ORD/Ecoregions/ok/ok_eco_pg.pdf (August 2018).