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ARTICLE

Sampling Characteristics and Calibration of Snorkel Counts to Estimate Stream Fish Populations

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Abstract
Snorkeling is a versatile technique for estimating lotic fish population characteristics; however, few investigators have evaluated its accuracy at population or assemblage levels. We evaluated the accuracy of snorkeling using prepositioned areal electrofishing (PAE) for estimating fish populations in a medium-sized Appalachian Mountain river during fall 2008 and summer 2009. Strip-transect snorkel counts were calibrated with PAE counts in identical locations among macrohabitats, fish species or taxa, and seasons. Mean snorkeling efficiency (i.e., the proportion of individuals counted from the true population) among all taxa and seasons was 14.7% (SE, 2.5%), and the highest efficiencies were for River Chub *Nocomis micropogon* at 21.1% (SE, 5.9%), Central Stoneroller *Campostoma anomalum* at 20.3% (SE, 9.6%), and darters (Percidae) at 17.1% (SE, 3.7%), whereas efficiencies were lower for shiners (*Notropis* spp., *Cyprinella* spp., *Luxilus* spp.) at 8.2% (SE, 2.2%) and suckers (Catostomidae) at 6.6% (SE, 3.2%). Macrohabitat type, fish taxon, or sampling season did not significantly explain variance in snorkeling efficiency. Mean snorkeling detection probability (i.e., probability of detecting at least one individual of a taxon) among fish taxa and seasons was 58.4% (SE, 6.1%). We applied the efficiencies from our calibration study to adjust snorkel counts from an intensive snorkeling survey conducted in a nearby reach. Total fish density estimates from strip-transect counts adjusted for snorkeling efficiency were 7,288 fish/ha (SE, 1,564) during summer and 15,805 fish/ha (SE, 4,947) during fall. Precision of fish density estimates is influenced by variation in snorkeling efficiency and sample size and may be increased with additional sampling effort. These results demonstrate the sampling properties and utility of snorkeling to characterize lotic fish assemblages with acceptable efficiency and detection probability, less effort, and no mortality, compared with traditional sampling methods.

Fish-sampling gear bias and quantitative gear comparison and calibration are important considerations in fisheries research and management. Sampling techniques and data collection form the scientific basis to assess and interpret fish population density, condition, and vital rates, as well as assemblage structure. Examination of the efficiency of sampling techniques

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allows for enhanced understanding of sampling properties and bias and may provide insight to reduce and quantitatively adjust techniques for future application (Peterson and Paukert 2009).

Visual estimation techniques have been used for decades to quantify animal populations; however, many uncertainties limit their accuracy and efficiency (Emlen 1971). Among visual techniques, snorkeling is an inexpensive, nonlethal, and versatile method for quantitatively sampling fish populations (Dolloff et al. 1996; Dunham et al. 2009), but observer efficiency is presumably influenced by environmental conditions and fish behavior. Water turbidity, flow rate, and temperature change temporally within and among streams and rivers, which may affect observer efficiency (Hillman et al. 1992). Observer training, experience, and fish identification skills may also affect efficiency of counts and the accuracy of characterizing assemblages (Dunham et al. 2009). Furthermore, changes in the composition of local fish assemblages in response to environmental conditions may be influenced by a variety of factors, including variable species behavior, habitat affinity, and life history (Kwak 1991; Lobb and Orth 1991; Grossman and Ratajczak 1998), which may affect snorkeling efficiency among seasons (Ensign et al. 1995; Korman et al. 2010).

Calibrating snorkel counts is important when the primary objective is estimating fish density, and a typical approach is to apply two gears concurrently and compare the relative catch. Other investigators have calibrated snorkel counts by comparing them with a standardized population-estimating procedure, usually multiple-pass electrofishing (Hankin and Reeves 1988; Mullner et al. 1998; Roni and Fayram 2000; Thurow et al. 2006), or mark–recapture methods (Slaney and Martin 1987; Orell and Erkinaro 2007; Pink et al. 2007). Multiple-pass electrofishing methods are most appropriate for application in small streams where block nets can be effectively deployed, but are less suitable for large streams or rivers. Mark–recapture methods have primarily been applied to game fish species (e.g., salmonids) that can survive capture, handling, marking, and recapture. Smaller, more sensitive fish species, such as small-bodied cyprinids, may be subject to variably high rates of sampling mortality or injury, especially when common electrofishing techniques are used (Holliman et al. 2003a, 2003b; Snyder 2003).

Faced with the challenge of working in a medium-sized river and with the objective to estimate sampling efficiency and density of nongame fish populations, we chose prepositioned areal electrofishing (PAE), a passive form of electrofishing, to calibrate snorkel counts. Prepositioned areal electrofishing has been used to effectively sample small- and medium-sized rivers (Bowen and Freeman 1998) and discrete macrohabitats, such as pools, riffles, and runs (Bain et al. 1985; Walsh et al. 2002; Schwartz and Herricks 2004), as well as diverse fish assemblages (Larimore and Garrels 1985; Grabowski and Isely 2007). Furthermore, based on its high rate of fish immobilization (98%: Bain et al. 1985), high efficiency (100%: Janac and Jurajda 2010), and low sampling bias (Ensign et al. 2002), we assumed that PAE provided the most accurate, but not perfect, estimate of the true fish population.

Our objectives in this assessment were to (1) determine whether PAE can be effectively applied as a comparative gear for calibrating snorkel counts, (2) estimate snorkeling efficiency among taxa in the fish assemblage both spatially and temporally, and (3) apply taxon-specific estimates of snorkeling efficiency from our empirical calibration to adjust strip-transect snorkel count data collected from a nearby study reach.

STUDY AREA

We evaluated the accuracy of snorkel counts for estimating nongame fish densities in a southern Appalachian Mountain river, the North Toe River, in Mitchell County, North Carolina, during fall 2008 and summer 2009. The North Toe River drains approximately 474 km^2 and is a high-gradient, medium-sized river that joins the Cane River to become the Nolichucky River, a tributary to the French Broad River, which ultimately flows west to the Tennessee River. We conducted our gear calibration study in a 0.5-km reach containing a diversity of pool, riffle, and run habitats.

We used the snorkeling efficiency estimates obtained from our calibration study to adjust snorkel counts from a more intensive survey we conducted 11 km downstream, during summer and fall, in the town of Spruce Pine, North Carolina, over a 1-km reach (Weaver 2010; Weaver and Kwak 2013). The native fish assemblage of the river is typical of the area and is composed of Smallmouth Bass *Micropterus dolomieu* and sunfishes *Lepomis* spp. as sport fishes that coexist with multiple species and families of coolwater and warmwater nongame fish. The river is also stocked seasonally by the North Carolina Wildlife Resources Commission with stream-dwelling salmonids to support popular recreational trout fisheries (NCWRC 2009; Weaver and Kwak 2013). We examined the entire fish assemblage, stratified into taxa, based on their habitat use, behavior, and morphological traits. These fish taxa included (1) Central Stoneroller *Campostoma anomalum*, (2) River Chub *Nocomis micropogon*, (3) shiners *Notropis* spp., *Cyprinella* spp., and *Luxilus* spp., (4) suckers Catostomidae, and (5) darters Percidae.

METHODS

Prepositioned areal electrofisher.—The PAE grid consisted of two 15-m lengths of 0.65-mm-diameter stainless steel cable that were spaced 1 m apart using two 7-cm-diameter PVC pipes to form an effective sampling area of 15 m^2. The grid was powered by AC from a 3,500-W generator and converter that regulated amperage output. The grid was connected to the power source by a 30-m electrical cord. We adjusted electric output prior to sampling to ensure fish immobilization.

Snorkeling calibration procedure.—During fall 2008 and summer 2009, we used standard macrohabitat classifications (Arend 1999) to select 12 transect sampling locations: four pools, four riffles, and four runs. One PAE sample and one snorkeling survey were conducted at each transect during both seasons. We sampled all transects within a 2-d period. For each transect, a homogenous area of macrohabitat was selected to encompass the entire grid sampling area. The grid was placed in the water parallel to flow, and a 15-min waiting period ensued to allow the sampling area to return to predisturbed conditions to minimize fright bias (Bain et al. 1985; Bowen and Freeman 1998). A single observer entered the water 5 m downstream from the grid, snorkeled slowly upstream through the center of the grid, and identified and counted all fish visible within and outside of the grid. A weighted marker was placed at each location of fish observed outside of the grid. The observer minimized counting fish twice by moving constantly through the transect keeping recorded individuals within peripheral vision. After passing through the grid, the observer exited the water, and another 15-min waiting period lapsed. The same observer snorkeled all transects during both seasons.

After the second 15-min waiting period, two dipnetters positioned themselves 5 m downstream from the grid. The grid was then electrified for 60 s, and all stunned fish within the grid were collected as both dipnetters moved upstream. Power to the grid was shut off, and dipnetters searched downstream to collect any remaining stunned fish. Captured fish were identified, counted, and released back into the river. After each transect was sampled by both techniques, the distance of the farthest identifiable fish was measured from the corresponding marker to the center of the grid, serving as an estimate of snorkeling sampling area and a sampling covariate for stream visibility for each transect. We measured water temperature (°C), dissolved oxygen (mg/L), specific conductivity (μS/cm), pH, and turbidity (NTU) using a Hydrolab model MS5 multiprobe datasonde and Surveyor 4a display unit.

Snorkeling efficiency.—The length of each snorkel transect was identical to the length of the PAE grid; however, because observers could generally see farther than the width of the PAE grid, the total area snorkeled was consistently larger than the area sampled by the PAE. Therefore, for each of the 12 transects sampled during each season, a strip-transect count density estimate was calculated from the count and respective total area sampled from each gear-type as

$$\hat{D}_j = \frac{\hat{C}_j}{(w_i \times l \times t)} \tag{1}$$

(Keast and Harker 1977), where density $\hat{D}$ for a particular fish species or taxon j is calculated as the count $\hat{C}$ divided by the product of the width w_i, length l, and number of transects t. The width of each snorkeling transect was two times the farthest fish observed, and that for the prepositioned areal grid remained constant at 1.0 m.

Snorkeling efficiency estimates $\hat{q}$ of a particular taxon j were calculated as a proportion by dividing the strip-transect count density estimate obtained by snorkeling ($\hat{D}_{js}$) by the corresponding density estimate obtained from PAE ($\hat{D}_{je}$) as

$$\hat{q}_j = \frac{\hat{D}_{js}}{\hat{D}_{je}}. \tag{2}$$

These snorkeling efficiency estimates represent the probability of detecting an individual from a particular fish taxon as a proportion of fish of that taxon present. Efficiency was calculated separately for fish taxa and macrohabitat types in a similar manner. The SE of efficiency estimates was calculated as a measure of precision following the equation for SE of a sample mean (Sokal and Rohlf 1981).

Statistical analysis.—We compared snorkel counts and PAE catch during fall and summer using Spearman's rank correlation. We assumed a positive monotonic correlation between snorkel counts and PAE catch. Our snorkeling efficiency estimates did not conform to a normal distribution (Shapiro–Wilk W-test: $P < 0.05$; Zar 1999), so we applied statistical procedures that did not assume a normal distribution. We fit a generalized linear model to test for biotic and abiotic influences on snorkeling efficiency (JMP Pro version 11.0, SAS, Cary, North Carolina). We modeled snorkeling count as a function of macrohabitat type, fish taxon, season, and $\log_e$(PAE count) using a binomial distribution and logit link function.

Fish density.—We applied our snorkeling efficiency estimates for each fish taxon to strip-transect counts from an intensive snorkeling survey in the same river that was designed to characterize the fish populations stratified among all macrohabitat types. The intensive survey consisted of 10 transects, each 30-m long, stratified by macrohabitat with transect widths based on the farthest fish observed during that sampling period (Weaver 2010). Adjusted density estimates were calculated as

$$\hat{N}_j = \frac{\hat{D}_j}{\hat{q}_j} \tag{3}$$

(Thompson and Seber 1994), where $\hat{N}$ is the adjusted density estimate of a fish taxon j, $\hat{D}$ is the strip-transect count density estimate (equation 1), and $\hat{q}$ is the snorkeling efficiency estimate for that taxon expressed as a proportion from equation (2). We derived variance approximations of the adjusted density estimates ($\hat{N}$) for a fish taxon j using the delta method (Williams et al. 2002) as

$$\operatorname{var}\left(\hat{N}_j\right) = \left(\frac{\hat{D}_j}{\hat{q}_j}\right)^2 \left[\frac{\operatorname{var}\left(\hat{D}_j\right)}{\hat{D}_j{}^2} + \frac{\operatorname{var}\left(\hat{q}_j\right)}{\hat{q}_j{}^2}\right], \tag{4}$$

and then calculated the associated SE of the adjusted density estimate as the square root of the variance. We then compared strip-transect count density estimates with adjusted strip-transect density estimates that were corrected for snorkeling

TABLE 1. Total fish counts by snorkeling and prepositioned areal electrofishing (number of fish) among fish taxa and macrohabitat types during fall 2008 and summer 2009 in 12 transects in the North Toe River, Mitchell County, North Carolina.

	Summer		Fall	
Variable	Snorkeling	Electrofishing	Snorkeling	Electrofishing
Fish taxon				
Shiners	28	100	42	153
Central Stoneroller	34	53	93	128
River Chub	24	29	19	43
Suckers	7	31	3	17
Darters	17	22	40	57
Total	110	235	197	398
Macrohabitat type				
Pool	23	70	76	158
Riffle	75	119	100	171
Run	12	46	21	69
Total	110	235	197	398

efficiency through empirical calibration at the taxon and assemblage levels.

RESULTS

During gear calibration, the total area sampled by snorkeling 12 transects was 504 m^2 during the summer and the farthest fish observed was at 1.40 m (2.80 m total width). During the fall the total area sampled was 900 m^2 and the farthest fish observed was at 2.50 m (5.00 m total width). The total area we sampled by PAE was constant between seasons at 180 m^2 (15 m^2 $\times$ 12 samples each season). We observed no stunned fish outside of the grid area while the grid was electrified, confirming that the voltage gradient was concentrated within the grid, a characteristic also observed by Bowen and Freeman (1998). During our intensive survey, the total area snorkeled was 1,116 m^2 (10 transects, each 30 m long, and the farthest fish was observed at 1.86 m) during the summer and 1,470 m^2 (10 transects, each 30 m long, and the farthest fish was observed at 2.45 m) during the fall. Among environmental variables measured during the calibration procedure, we found higher temperatures (21.5°C versus 17.2°C), higher turbidity (6.1 versus 2.4 NTU), lower dissolved oxygen (9.2 versus 9.7 mg/L), and higher pH (8.0 versus 7.7) during summer sampling than in the fall.

We obtained consistently lower total fish counts from snorkeling than from those obtained by PAE for all fish taxa, macrohabitats, and seasons (Table 1). In 4 of 24 total transects sampled, we identified one fish taxon during snorkeling that was not captured by electrofishing. Excluding those exceptions, if we assume that electrofishing detects all fish taxa present, then snorkeling detection probability averaged 58.4% (SE, 6.1%) among all taxa and seasons and was equivalent between seasons (summer: 58.5% [SE, 6.8%]; fall: 58.4% [SE, 11.0%]; Table 2).

Snorkeling Efficiency

Spearman's rank correlation indicated that snorkel counts and electrofishing catch among fish taxa were significantly correlated within seasons for both seasons (summer: $r_s = 0.725$, $P < 0.0001$, $N = 60$; fall: $r_s = 0.657$, $P < 0.0001$, $N = 60$; Figure 1).

Mean snorkeling efficiency among all taxa and seasons was 14.7% (SE, 2.5%) and ranged from 4.0% to 30.3% (Table 3). Between seasons, mean snorkeling efficiency among taxa was 11.2% (SE, 3.1%) during the fall, ranging from 4.0% to 19.5%, and was 18.1% (SE, 3.9%) during the summer, ranging from 9.1% to 30.3%. We observed relatively low mean efficiencies for suckers and shiners (6.6% and 8.2%, respectively) and higher efficiencies for Central Stoneroller and River Chub (20.3% and 21.1%, respectively). Among macrohabitats, runs had the lowest efficiency (9.4%) relative to pool (13.7%) and riffle (17.7%) habitats. However, a generalized linear model did not significantly explain the variance in snorkeling

TABLE 2. Snorkeling detection probability (%) among fish taxa and mean detection probability (SE in parentheses) between seasons, assuming that prepositioned areal electrofishing detected all available taxa in each transect and season sampled ($N = 12$ each season) in the North Toe River, North Carolina.

	Detection probability (%)	
Fish guild	Summer	Fall
Shiners	72.7	55.6
Central Stoneroller	66.7	42.9
River Chub	62.5	75.0
Suckers	33.3	28.6
Darters	57.1	90.0
Mean	58.5 (6.8)	58.4 (11.0)

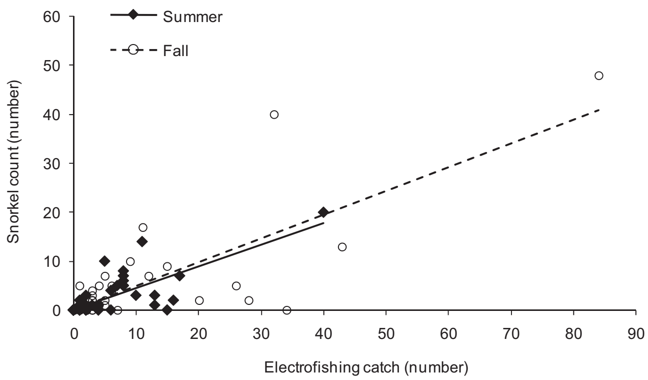

FIGURE 1. Total snorkel count versus total prepositioned areal electrofishing catch for five taxa in 12 transects during each season, fall 2008 ($N = 60$) and summer 2009 ($N = 60$), in the North Toe River, North Carolina.

efficiency among macrohabitat type, fish taxon, or sampling season ($P > 0.05$).

Fish Density

Strip-transect count density estimates for combined fish taxa were 1,030 fish/ha during the summer and 1,769 fish/ha during the fall (Table 4). Adjusted strip-transect count density estimates were 7,288 fish/ha (SE, 1,564) during the summer and 15,805 fish/ha (SE, 4,947) during the fall. Overall, strip-transect count density estimates and adjusted strip-transect count density estimates were lower for all fish taxa during summer than during fall. Shiner and Central Stoneroller estimates were most abundant followed by darters and River Chub, and suckers were the least abundant.

DISCUSSION

We quantified snorkeling efficiency for the fish assemblage of a medium-sized southern Appalachian Mountain river using gear comparison during two seasons and then adjusted strip-transect snorkeling counts into density estimates using taxon-specific efficiency estimates. No covariate that we examined significantly explained the variance in snorkeling efficiency, which suggests there are distinct differences in fish behavior. Our mean estimate of snorkeling efficiency (14.7%) is similar to those for trout and salmon (16.0%: Roni and Fayram 2000; 12.5%: Thurow et al. 2006); however, among fish taxa that we sampled, efficiency ranged from 4% to 30%, further emphasizing the need to calibrate gears at the population or taxon level for accuracy of density estimates at the community level. We suggest that calibrating snorkeling efficiency with PAE is a practical approach to estimate fish density in medium-sized rivers where conventional sampling techniques may not be possible.

Our estimates of snorkeling efficiency (mean, 14.7%; range, 4–30% among taxa) were generally lower than those of other stream fish sampling techniques. Peterson and Rabeni (2001) found that sampling efficiency of a 1-m^2 quadrat varied widely among fish families and ranged from 31% to 84%. Multiple-pass removal sampling using backpack electrofishing was 63–97% efficient (Wiley and Tsai 1983; Rodgers et al. 1992; Meyer and High 2011), but efficiency modeled for single-pass backpack electrofishing ranged from 7% to 29% among taxa (Price and Peterson 2010). Multiple seine-haul efficiency estimates in Piedmont and coastal streams were 70–79% (Weinstein and Davis 1980; Wiley and Tsai 1983). The utility of these other techniques in a medium-sized river, such as the North Toe River that we studied, is usually logistically problematic and hindered by water depth (e.g., for seining, backpack electrofishing) and maneuverability (e.g., for boat electrofishing: Curry et al. 2009). Thus, despite generally lower efficiency, the snorkeling technique provides a practical method for characterizing lotic fish assemblages when other methods are inappropriate.

Our snorkeling efficiency estimates among fish taxa and corresponding adjusted strip-transect count density estimates may

TABLE 3. Mean snorkeling efficiency estimates (percent of individuals sampled) and SE among fish taxa and macrohabitat types during fall 2008 and summer 2009 seasons in the North Toe River, North Carolina.

	Summer			Fall		
Variable	Efficiency (%)	SE	N	Efficiency (%)	SE	N
Fish taxon						
Shiners	9.82	2.69	11	6.54	3.54	9
Central Stoneroller	21.10	13.22	3	19.49	13.88	7
River Chub	30.32	11.01	8	11.87	4.17	8
Suckers	9.14	5.67	7	4.00	2.90	7
Darters	20.09	6.89	6	14.16	2.51	10
Macrohabitat type						
Pool	15.32	7.85	12	12.04	2.66	17
Riffle	20.88	3.59	14	14.54	7.06	14
Run	13.59	6.56	9	5.17	2.33	10

TABLE 4. Comparison of strip-transect count and adjusted strip-transect count density estimate (mean ± SE) among fish taxa for 10 transects during intensive snorkeling surveys conducted during fall 2008 and summer 2009 in the North Toe River, North Carolina.

	Strip-transect count (fish/ha)				Adjusted strip-transect count (fish/ha)			
Fish taxon	Summer mean	SE	Fall mean	SE	Summer mean	SE	Fall mean	SE
Shiners	439.1	29.8	455.8	18.3	4,469.2	1,259.7	6,969.2	3,775.4
Central Stoneroller	277.8	26.8	816.3	52.3	1,316.2	834.3	4,188.4	2,995.9
River Chub	98.6	5.4	210.9	11.1	325.1	119.4	1,775.1	630.7
Suckers	17.9	1.8	47.6	4.1	196.1	187.2	1,190.5	867.7
Darters	197.1	13.0	238.1	9.5	981.3	336.8	1,681.5	305.7
Total	1,030.5	60.2	1,768.7	81.2	7,287.9	1,563.9	15,804.7	4,947.0

have been influenced by several environmental and behavioral variables. Some riverine fish exhibit seasonal migration in response to declining temperature (Jonsson 1991), as well as increases in cryptic behavior and a greater tendency to seek cover in reaction to lower water temperatures and higher water velocities (Gibson 1978; Taylor 1988). We found reduced efficiency of snorkel counts with lower water temperature, suggesting that fish can increase cover association and cryptic behavior during fall compared with summer (Hillman et al. 1992; Rodgers et al. 1992). Reduced efficiency may have also been related to an increase in fish density, as we estimated more than twice as many fish per area during the fall compared with the summer, which may have caused the observer to overlook some fish while snorkeling.

The portion of unexplained variance in our correlations between snorkeling counts and electrofishing catch ($r_s = 0.66$–0.73) is likely due to differences in fish behavior among taxa and sizes and associated variability in detection probability between snorkeling and electrofishing. Other investigators have reported high positive correlations ($r^2 > 0.90$) between visual counts and multiple-pass electrofishing removal estimates (Hankin and Reeves 1988; Mullner et al. 1998; Wildman and Neumann 2003); however, those studies focused exclusively on salmonids. We demonstrated clear differences in detection probability among stream fish taxa and among individual fish within a taxon (i.e., efficiency), highlighting the importance of examining fish sampling efficiency and detection probability of sampling techniques at multiple organizational scales, especially if research or management objectives are at the assemblage level.

A challenge in implementing the strip-transect count method is determining the boundaries of the transect width. Our strip-transect count estimate relied upon measurements of the fish seen farthest from the center line of observation ($0.5w_i$, equation 1) to standardize counts per area. We assumed that (1) this index correctly measures the maximum visibility distance of the observer, (2) all fish taxa have an equal probability of being observed at this distance, and (3) distances are measured accurately. We acknowledge that violations to these assumptions may result in under- or overestimation of fish density. However, the measurement value of the farthest fish serves as an index of observer visibility, which may be an important factor in future studies that examine spatial and temporal variability in visual estimates of fish density. Alternative indices for observer visibility could include water turbidity or Secchi disk depth (Ensign et al. 1995; Mullner et al. 1998), but our index integrates multiple instream factors that influence visibility in situ (e.g., geomorphology, substrate composition, instream cover, as well as water turbidity, color, and light conditions) and provides an exact transect width measurement.

Our fish density estimates are within the ranges of those obtained for other riverine fishes (Ensign et al. 1995; Hewitt et al. 2009), although notable differences exist. Hewitt et al. (2009) estimated density of the endangered Cape Fear Shiner *Notropis mekistocholas* in the Cape Fear River basin, North Carolina, to range from 795 to 1,393 fish/ha using the strip-transect count method. Our strip-transect counts (unadjusted for efficiency) for all shiners were 439.1 and 455.8 fish/ha for the summer and fall, respectively. The difference in density estimates between our sampling and that of Hewitt et al. (2009) may be due to study site differences, as our sampling was conducted in a high-gradient mountain river (lower productivity) versus their sampling in a Piedmont river (higher productivity), reflecting actual population differences rather than variation in sampling efficiency. Ensign et al. (1995) estimated mean densities of 5–272 fish/ha for Black Jumprock *Moxostom cervinum*, 3–163 fish/ha for Roanoke Logperch *Percina rex*, and 79–2,360 fish/ha for Roanoke Darter *Etheostoma roanoka* over various sampling sites using line-transect distance sampling. Our density estimates derived from strip-transect counts adjusted for efficiency are much higher than those estimates based on actual counts, and we consider the adjusted estimates to be more accurate estimates of actual fish density than those proportional estimates based on unadjusted counts (Hayes et al. 2007; Peterson and Paukert 2009).

The use of PAE to calibrate snorkel counts appears to be a viable approach when other sampling techniques are inappropriate. Fish mortality from electrofishing, especially if AC power is employed, may pose a concern, especially when studying rare or endangered species. An initial calibration study, however, may provide sufficient efficiency estimates to apply to more intensive or extensive visual surveys to quantify fish populations over time without introducing the acute or cumulative effects of electrofishing mortality. This is a highly applicable approach if sampling mortality could bias results of research or management assessments. Precision of fish density estimates adjusted for snorkeling efficiency (expressed as SE here) is influenced by spatial and temporal variation in efficiency and the effect of sample size. Thus, the precision of future fish density estimates may be increased by larger sample sizes in developing calibration relationships.

Our study further highlights the utility of gear calibration when conducting underwater visual surveys (Dolloff et al. 1996; Dunham et al. 2009; Peterson and Paukert 2009). Our specific snorkeling efficiency estimates may be appropriately applied to related studies of similar fish assemblages under comparable environmental conditions or for imprecise approximations of fish abundance. Spatial, temporal, and observer variation in efficiency, however, may compel integration of gear comparison methods or environmental covariates into site- or water-body-specific efficiency models to more accurately estimate fish abundance, depending on sampling objectives. Our findings support the conclusion that stream fish assessments over large spatial areas can be conducted with acceptable efficiency and detection probability, less effort, and no mortality with visual sampling methods compared with traditional sampling methods such as electrofishing.

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