# Capture Avoidance of Smallmouth Bass during Multi-pass Depletion Sampling in Virginia Rivers

**Stephen J. Reeser,** *Virginia Department of Game and Inland Fisheries, P.O. Box 996, Verona, VA 24482*

**George C. Palmer,** *Virginia Department of Game and Inland Fisheries, 1796 Highway Sixteen, Marion, VA 24354*

*Abstract:* When estimating population size of smallmouth bass (*Micropterus dolomieu*) using the multi-pass removal method with electrofishing, understanding the significance of capture avoidance is important. One-hundred-fifty smallmouth bass were tagged with external radio transmitters and monitored during depletion sampling in seven different river reaches in Virginia. Capture avoidance of radio-tagged smallmouth bass during electrofishing averaged 33.7% (SE = 5.75%). Avoidance appeared to be random across the sample reaches and there were no significant correlations between capture avoidance and fish length, season, river, or physical dimensions of the sample reaches. Emigration from the sample reaches during depletion sampling was observed. However, no pattern in upstream or downstream movement was documented. The findings from this study suggest that when using the multi-pass electrofishing technique to estimate population size, capture avoidance of the target species should be evaluated.

*Key words:* smallmouth bass (*Micropterus dolomieu*), electrofishing, depletion, telemetry, capture avoidance

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 64:172–178

Understanding population dynamics is essential in managing fish populations. Electrofishing is one method commonly used to evaluate fish populations in lotic systems (Peterson et al. 2009, Rowe et al. 2009). Although electrofishing produces biased estimates of size structure (Reynolds 1996, Dolan and Miranda 2003) and seasonal variation in catch (Sammons and Bettoli 1999), it is a widely accepted method to sample black bass in lotic systems (Odenkirk and Smith 2005, Humston et al. 2009).

Multi-Pass removal electrofishing has been used to estimate densities and biomass of several freshwater lotic fish species including smallmouth bass (*M. dolomieu*) (Odenkirk and Smith 2005) and brook trout (*Salvelinus fontinalis*) (Moore et al. 1983). It is recognized that when estimating density and biomass using the depletion method the assumptions of constant sampling effort, equal probability of capture, and a closed population may be violated (Riley and Fausch 1992, Van Den Avyle and Hayward 1999, Rosenberger and Dunham 2005). Population estimates derived from the depletion method may also be compromised by biotic and abiotic variables that affect capturability (Peterson et al. 2004).

Smallmouth bass make up a major component of the black bass resource in Virginia and are the second most sought after species by Virginia anglers (O'Neill 2001). Fisheries biologists with the Virginia Department of Game and Inland Fisheries (VDGIF) have intensively researched lotic smallmouth bass populations with the intent of maximizing the angling potential of these resources (Smith and Kauffman 1991, Odenkirk and Smith 2005, Smith et al. 2005). Telemetry studies have been conducted to document movements (Venditti et al. 2000, Popoff and Neumann 2005), habitat preferences (Raibley et al. 1997), mortality rate (Young and Isely 2004), and angler interactions (Margenau 1987) of several freshwater fish species. Specifically, radiotelemetry has been used with riverine smallmouth bass to determine movements (Van Arnum et al. 2004), home range (Lyons and Kanehl 2002), habitat selection (Todd and Rabeni 1989), and angler displacement (Bunt et al. 2002). However, only limited work has been done using radiotelemetry to assess violations of population estimators (Zehfuss et al.1999) and capture avoidance from electrofishing (Grabowski et al. 2009).

Recent VDGIF management of smallmouth bass in Virginia rivers has focused on deriving population estimates using the depletion removal method (Odenkirk and Smith 2005). To test for violations of general assumptions that are possible with this type of population estimator, it was necessary to monitor smallmouth bass behavior during intensive sampling efforts in Virginia's rivers. One way to accomplish this was to tag and track multiple adult smallmouth bass within river reaches during depletion removal sampling. The goal of this study was to estimate capture avoidance of radio-tagged smallmouth bass during depletion sampling. We define capture avoidance as fish that directly avoid capture from electrofishing within designated sampling reaches or vacate the sampling reach during depletion sampling. The objectives were: (1) estimate the percent capture avoidance of radio-tagged smallmouth bass in different study reaches during depletion sampling, (2) measure emigration or immigration of radio-tagged smallmouth bass in relation to the study reaches during depletion sampling, and (3) correlate capture avoidance with depletion site characteristics and smallmouth bass length.

## Study Area

Seven study sites were located on four rivers in Virginia. Two sites were sampled in spring 2004 on the North Fork Holston River and two sites on the New River in 2005. Two sites were located on the James River and one on the Shenandoah River in fall 2007. Sites ranged from 0.8 to 9.9 ha of surface area, and average river widths ranged from 30 to 118 m (Table 1). Depth at all sites varied but never exceeded 4.2 m. The upper and lower boundaries of each site consisted of a large riffle section that served to limit movement of fish but did not completely block movement.

**Table 1.** Physical dimensions of sample reaches and electrofishing (EF) boat density where multi-pass electrofishing removals were conducted in Virginia rivers 2004–2007.

| River | Site | Length (m) | Max width (m) | Max depth (m) | Area (ha) | EF boats | Boat density[a] |
|---|---|---|---|---|---|---|---|
| Holston | Bridgeman | 267 | 30 | 2.1 | 0.8 | 7 | 4.28 |
| Holston | Weber City | 817 | 60 | 3.6 | 4.9 | 8 | 7.50 |
| New | Whitethorn | 455 | 118 | 3.0 | 5.4 | 14 | 8.43 |
| New | Eggleston | 466 | 113 | 2.4 | 5.3 | 15 | 7.53 |
| James | Buchanan | 1168 | 74 | 2.4 | 8.6 | 14 | 5.28 |
| James | Lick Run | 715 | 39 | 2.7 | 2.8 | 7 | 5.57 |
| Shenandoah | Comptons | 1346 | 72 | 4.2 | 9.7 | 10 | 7.20 |

a. meters of stream width per electrofishing boat

## Methods

### Radiotelemetry

One-hundred-fifty externally mounted radio transmitters (Advanced Telemetry Systems, Isanti, Minnesota; 151.013 – 151.603 MHz frequency range; approximately 2.5 g, pulse rate 41 ppm, battery life 36 days) were used to track adult smallmouth bass during the depletion studies. Of the 150 transmitters, 30 were used at two sites (15 at Weber City and 15 at Bridgeman) in the North Fork Holston River in April 2004. Sixty were used at two sites (30 at Whitethorne and 30 at Eggleston) in the lower New River in September 2005. Twenty were used at each of three sites (Buchanan, Lick Run, and Compton) in the James and Shenandoah rivers in fall 2007. Radio signals were received using a scanable radio receiver and directional loop antenna (Advanced Telemetry Systems).

Smallmouth bass collected for radio transmitters were captured using a boat electrofishing unit with pulsed-DC output (Smith-Root, Vancouver Washington). All radio-tagged fish were collected from within the sample reaches prior to depletion sampling. Radio transmitters were attached 7–14 days prior to depletion sampling. Fish were held in livewells during transmitter attachment and released in the middle of the sample reach following radio and transmitter signal testing. Transmitters were attached directly below the anterior end of the dorsal fin and mounted flush against the body. Transmitters were attached with thin wire cables connected to the transmitter by inserting them through the fishes back and locked in place with washer disks and crimped. Total length of tagged fish ranged from 211–551 mm (mean = 331 mm). All fish that were tagged with radio transmitters were also marked with a single numbered anchor tag attached along the dorsal fin.

Locations of radio-tagged fish in and around the study sites were observed immediately prior to depletion sampling. All tagged fish locations in the sample reach and within 500 m of the site were recorded and mapped using a global positioning system and a site map. This allowed for an initial assessment of the numbers of radio-tagged fish within the site boundaries and fish above or below the site that may migrate into or out of the site during depletion sampling. After the tagged fish were located, the first depletion sampling pass was made. All fish, including radio-tagged fish, were collected and removed from the site and held in large livewells. All radio tags and anchor tags were removed from the fish after capture. Tagged fish were located after the completion of each depletion run and their location was recorded and mapped. Tracking preceded each depletion run and a final tracking run was made when the depletion sampling was concluded. Data collected on tagged fish consisted of location at the beginning of the sample, during depletion sampling, and whether or not the fish avoided collection. Transmitter signals located within the sample reaches that showed no movement prior to or during the depletion sampling were assumed to be deceased fish or shed transmitters and were omitted as fish available for capture. This was reinforced by continued tracking after depletion sampling with no observed movement. Captured fish that had shed radio tags were easily identified by the scars left from the tagging procedure and by the corresponding number on the anchor tag.

### Electrofishing Depletion Technique

Electrofishing collections involved a depletion technique using 10–16 electrofishing boats simultaneously shocking upstream from the lower to the upper point of each study site. Boat electrofishing units (Smith-Root, Vancouver, Washington) utilized pulsed-DC output. One or two netters per boat collected fish, while boats remained parallel in a constant upstream movement. Time to complete a single depletion run was recorded for data analysis. All fish collected were placed in livewells during runs and held in 1136-L tanks following the data collection. Fish were identified to species and individual length and weight were recorded. Following the depletion sampling all fish were released. The lapsed time between electrofishing passes never exceeded 30 min. The longest time lapse always occurred after the initial electrofishing pass, and time between subsequent passes decreased dramatically. An acceptable depletion was obtained after the 95% confidence interval of the estimated population was obtained using computer software (Van Deventer 1989) in the field.

### Data Analysis

Location data analysis consisted of presence or absence and relative position of tagged fish within the study sites. Locations of radio-tagged fish were recorded on site maps before and after each electrofishing pass. Fish avoidance of capture was documented by monitoring the locations of radio-tagged fish during and after depletion runs. This was accomplished by having a chase boat follow directly behind the electrofishing boats monitoring radio-tagged fish movements.

Statistical analysis was performed on three sets of data; (1) percent of all fish that avoided capture for each reach, (2) percent of fish that avoided capture and remained within the sample reach, and (3) percent of fish that emigrated from the sample reach. Both parametric (linear and multiple regression) and nonparametric (Pearson correlation) tests were used to determine if any physical site characteristics or other variables significantly influenced capture avoidance. The site characteristics used in the analysis included: length, maximum width, wetted area, and maximum depth. We also determined if the number of electrofishing boats used or "boat density" (coverage) influenced capture avoidance of smallmouth bass. We define boat density as the number of boats divided by the average width of the sample site. For some analysis the arcsin (θ) of percentages was used. Capture probability was calculated using MicroFish 3.0 software (Van Deventer 1989) as described in Van Deventer and Platts (1983). Significance for all statistical tests was determined at the alpha level of 0.05.

## Results

One hundred ten (73%) of the original 150 radio-tagged smallmouth bass were located within the seven sample reaches prior to depletion sampling and were available to capture. Of the 40 radio-tagged smallmouth bass that were not available to capture, 23 were not located within the sample reach or in the immediate area on the day of depletion sampling, nine were located within close proximity to the sampling reaches, and eight were assumed to be deceased or shed their tags based on observations during and after depletion sampling.

The maximum number of electrofishing passes needed to obtain the desired depletion at the seven sample locations was four. Three electrofishing passes were conducted on four samples reaches, and four passes were completed on three reaches. Capture probability for adult smallmouth bass in this study ranged from 0.5 to 1.0 (mean = 0.81) (Table 2).

Capture avoidance of radio-tagged smallmouth bass averaged 33.7% (range = 13%–53.3%; SE = 5.75%) among the seven sample sites (Table 2). Capture of radio-tagged smallmouth bass did not decrease uniformly with successive electrofishing passes at all sample reaches (Table 2). Forty-seven percent of the radio-tagged fish in the sample reaches at the start of depletion sampling were captured during the first electrofishing pass (range = 20%–64%). Emigration of radio-tagged smallmouth bass from the sample reaches during deletion sampling averaged 13.46% (range = 0–33.3%; SE = 4.54%). Nine emigrating fish moved downstream, three fish moved up-

**Table 2.** Statistics for radio-tagged smallmouth bass captured or monitored during multi-pass electrofishing removals on Virginia rivers 2004–2007.

| Site | Fish tagged | Radios in site at start | Recap pass 1 | Recap pass 2 | Recap pass 3 | Recap pass 4 | p[a] | Total recap | Radios remain | Radios emigrate | Percent capture avoidance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BM | 15 | 9 | 4 | 2 | 0 | | 0.75 | 6 | 1 | 2 | 33.30% |
| WC | 15 | 12 | 5 | 0 | 1 | | 1.00 | 6 | 4 | 2 | 50.00% |
| WT | 30 | 22 | 13 | 5 | 0 | | 0.78 | 18 | 2 | 2 | 18.00% |
| EG | 30 | 22 | 13 | 3 | 3 | 1 | 0.62 | 20 | 0 | 3 | 13.00% |
| LR | 20 | 15 | 7 | 0 | 2 | | 1.00 | 9 | 6 | 0 | 40.00% |
| BC | 20 | 15 | 3 | 2 | 1 | 1 | 0.50 | 7 | 3 | 5 | 53.30% |
| CP | 20 | 14 | 9 | 0 | 1 | 0 | 1.00 | 10 | 4 | 0 | 28.60% |
| Total | 150 | 110 | | | | | | 76 | 20 | 14 | |
| Average | | | | | | | | 0.81 | | | 33.70% |
| % of total radios in all sites at start | | | | | | | | 69% | 18% | 13% | |

p[a] = capture probability

stream, and it was never verified which direction two fish left one sample reach. One individual fish emigrated downstream out of the sample reach during depletion sampling, and then immigrated back into the sample reach before the end of the depletion sampling. We observed eight fish (across four different sites) that located themselves just downstream of the sample reaches (<150 m) prior to the onset of the depletion sampling and never moved upstream immigrating into the sampling site during the operation. Ten radio-tagged fish shed their tags at one site on the New River, where dense submerged aquatic macrophytes covered much of the sample reach. This was the only site where tag loss was observed.

Using transmitter signals, movement of the 20 (18%) radio-tagged fish that remained within the sample reaches during depletion sampling was documented by changing fish locations. These fish avoided capture. Some avoided capture by seeking refuge in deep water (>2.7 m) pockets within the sample reaches, thus reducing vulnerability to boat electrofishing. Some fish may have avoided capture by seeking the sanctuary of large boulders in the stream channel or undercut banks containing woody debris. Two radio-tagged fish were captured (transmitter still attached) using electrofishing gear within one original sampling reach 40 d after the completion of the study. In addition, one radio-tagged fish was recaptured (with transmitter) 10 mo post study. All three recaptures were fish that remained within the sample reaches during the depletions and were located within the same sample reaches post study.

No significant relationship between physical characteristics of sample sites and total capture avoidance was documented using the Pearson correlation test (Table 3). Two weak correlations were identified; one between percent avoidance and site width ($P=0.135$) and another between the number of radio-tagged fish within the reach at the start of the depletion removal and capture avoidance ($P=0.091$). Using linear regression (Figure 1) and multiple regression analysis (Table 4), we were not able to detect any significant influences of site characteristics on capture avoidance. More detailed analyses were made in which radio-tagged fish that avoided capture were separated into two groups: (1) fish that emigrated from the reaches, and (2) fish that remained within the reaches and avoided capture. A Pearson Correlation test revealed a negative relationship between site area and the percentage of radio-tagged fish that emigrated from the sample reaches ($P=0.009$) (Table 5). Least squares linear regression showed a positive relationship between site area and percent tagged fish that avoided capture and remained within the sample reach ($r^2=0.85$; $P=0.003$) (Table 6). There was also no correlation between total fish length and capture avoidance of the radio-tagged fish. We ran a two sample t-test and found no significant difference in the

**Table 3.** Pearson product moment correlation coefficient for independent variables vs. percent capture avoidance of radio-tagged smallmouth bass from seven river reaches.

| | Percent avoidance | |
|---|---|---|
| **Independent variable** | **Correlation value** | ***P* - value** |
| Site depth | 0.055 | 0.907 |
| Site width | −0.623 | 0.135 |
| Site area | 0.087 | 0.853 |
| *n* EF boats | −0.430 | 0.335 |
| Boat density | −0.487 | 0.267 |
| *n* Radios at start | −0.687 | 0.091 |

**Table 4.** Stepwise multiple regression model for site characteristics vs. percent capture avoidance.

| | Dependant variable = Percent capture avoidance | |
|---|---|---|
| **Independent variables** | **t-value** | ***P* - value** |
| Site depth | 0.12 | 0.907 |
| Site length | 1.20 | 0.283 |
| Site width | −1.78 | 0.135 |

**Table 5.** Pearson product moment correlation coefficient for independent variables vs. percent of radio-tagged smallmouth bass that avoided capture by emigrating from river reaches or percent remaining within the reaches and avoiding capture.

| | Percent emigrated | |
|---|---|---|
| **Independent variable** | **Correlation value** | ***P* - value** |
| Site depth | −0.5447 | 0.206 |
| Site width | −0.0590 | 0.900 |
| Site area | −0.8770 | 0.009 |
| Boat density | −0.3324 | 0.466 |
| | **Percent avoided capture (remained in reach)** | |
| Site depth | 0.4897 | 0.265 |
| Site width | −0.6090 | 0.147 |
| Site area | 0.5158 | 0.236 |
| Boat density | −0.2141 | 0.645 |

**Table 6.** Least squares linear regression analysis for percent radio-tagged smallmouth bass from seven sample reaches that emigrated from reaches or remained within sample reaches and avoided capture vs. sample reach characteristics and electrofishing boat coverage.

| Dependent variable | Independent variable | $r^2$ | *P*-value |
|---|---|---|---|
| θ % Emigrated | Site length | 0.29 | 0.2123 |
| | Site width | 0.41 | 0.1216 |
| | Site depth | 0.23 | 0.2748 |
| | Site area | 0.15 | 0.3862 |
| | Boat density | 0.06 | 0.5701 |
| θ % Avoided capture (remained in sample reach) | Site length | 0.06 | 0.5838 |
| | Site width | 0.01 | 0.8529 |
| | Site depth | 0.31 | 0.1981 |
| | Site area | 0.85 | 0.0033 |
| | Boat density | 0.02 | 0.7228 |

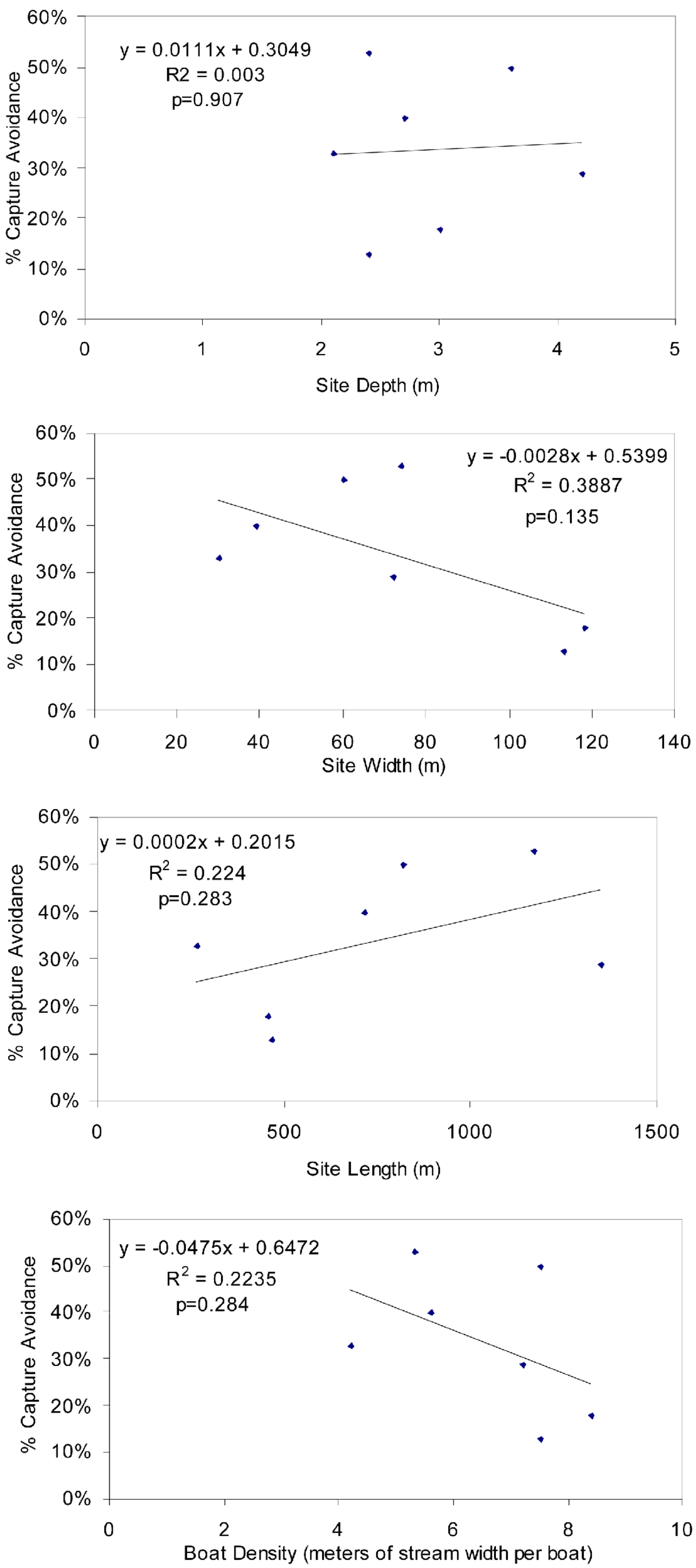


**Figure 1.** Relationship between sample site dimensions and boat density with total capture avoidance for radio-tagged smallmouth bass in seven Virginia rivers 2004–2007.

mean length of fish that were captured and fish that avoided capture ($t=1.98$, $P=0.90$, $DF=108$). Multiple statistical tests using raw numbers and transformed data failed to significantly explain how sample reach dimensions, electrofishing boat density, or fish length influenced electrofishing capture avoidance of smallmouth bass in this study. Capture avoidance appeared to be completely random across all the sample sites.

## Discussion

In Virginia, significant effort has been given to managing smallmouth bass in the state's rivers. Odenkirk and Smith (2005) described the depletion removal technique on these mid-size rivers and reported associated population estimates and capture probabilities for smallmouth bass generated from the technique. This study was initiated to measure the magnitude of sampling error that was occurring during these depletion removal surveys and help improve smallmouth bass population estimates.

The general assumptions that are made when calculating a population estimate using the multi-pass depletion removal method include: (1) the population is "closed," meaning there is no immigration or emigration of individuals into the study site during the sampling event; (2) all individuals exhibit equal opportunity to be captured; and (3) capture probability remains constant between electrofishing passes (Peterson and Cederholm 1984). When these general assumptions are sound, the generated population estimate is assumed to be sound. However, when the assumptions are violated, the model may not produce sound population estimates.

Fisheries researchers have estimated capture probability (Riley and Fausch 1992, Dauwalter and Fisher 2007), capture efficiency (Peterson et al. 2004), and sampling efficiency (Rosenberger and Dunham 2005) in regards to multi-pass removal electrofishing in lotic environments. However, these published studies were all conducted in smaller streams (<10 m in width) where block nets were used to ensure a "closed system" study reach.

We were knowingly violating the closed population assumption in this study. All stream reaches were >10 m in width and had no barriers to block fish emigration or immigration. The river width and water volume/velocity made it impractical to set block nets at the upstream and downstream end of our sample reaches as is recommended in smaller lotic systems when using electrofishing methods (Peterson et al. 2005). In order to limit or control the severity of this violated assumption, sample reaches were selected that contained some type of natural barrier at the upstream and downstream boundary that could impede fish movement. These were primarily shallow riffles or bedrock ledges, and sample reaches were long in attempts to reduce emigration from the site. Additionally, we wanted to measure the extent of this violation and adjust our population estimates accordingly. We followed the recommendation of Pine et al. (2003) and used telemetry in conjunction with a tagging/population study to determine the rate and extent of emigration from the study site. We duplicated the electrofishing removal methods for smallmouth bass described by Odenkirk and Smith (2005) in mid-sized rivers where their sample reaches were similar to those reported in this study and determined that capture avoidance was significant, between 13% and 53% for radio-tagged smallmouth bass. On average, 33.7% of the radio-tagged smallmouth bass at the seven sites in this study eluded capture. This amount of capture avoidance impacts the accuracy of the data produced from these depletion samples.

While capture avoidance of smallmouth bass did occur in our study, we did not find any significant relationships that could explain how emigration from sample reaches or avoidance of electrofishing within sample reaches was influenced by fish length, sampling effort, or site dimensions. Other researchers have documented the effects of fish size (Anderson 1995), water depth (Dauwalter and Fisher 2007), stream habitat (Peterson et al. 2004), and fish behavior (Grabowski et al. 2009) on electrofishing capturability, but we found no statistically significant cause we could correlate to the amount of capture avoidance observed in this study. The possibility remains that fish may "learn" to avoid capture after successive electrofishing attempts. Similar studies show that capture probability of larger smallmouth bass decreased with successive electrofishing passes in Oklahoma streams (Dauwalter and Fisher 2007). In addition, Peterson et al. (2004) reported that capture efficiency of two salmonid species decreased with successive electrofishing passes in 1st to 3rd order streams in Idaho and Montana. However, in our study, emigration of radio-tagged fish followed no discernable pattern. Were fish avoiding capture because our electric field was not completely covering the available habitat? Our methodology was to deploy enough electrofishing boats to have electric fields overlap and form a uniform barrier of electricity across the wetted width of the sample reaches. However, based on previous experiences with our sampling gear in these rivers, our assumptions were that the effective depth range needed to capture fish would not exceed 2.7 m and that there were no significant "gaps" in the electric field across the width of the reaches. Making successive electrofishing passes as quickly as possible to minimize tagged bass movement in or out of the sample reach may have attributed to increased capture avoidance in our study. A study by Cross and Stott (1975) recommended allowing one hour between electrofishing passes. While working with juvenile coho salmon, Peterson and Cederholm (1984) noted that a minimum of one hour between electrofishing passes allowed catchability levels to return to where population estimates were acceptable using the removal method. In our study, the parameters we examined did not explain why radio-tagged smallmouth avoided capture. This does not change the findings of the study that capture avoidance of the targeted species did occur during the sampling period and in significant amounts.

On average, 33.7% of the radio-tagged smallmouth bass at the seven sites in this study eluded capture. This amount of capture avoidance by the targeted species will lead to a population estimate that would misrepresent the true population size within the sampling area. We suggest that fisheries managers develop a plan to measure capture avoidance, emigration, and immigration for the species they are targeting when using multi-pass electrofishing methods in open, lotic environments. Once capture avoidance has been quantified, population estimates can be adjusted to more accurately reflect the true size of the population in open systems. Measuring capture avoidance will allow for improved accuracy of data collected.

## Acknowledgments

This study was funded through Federal Aid in Sportfish Restoration Grant F-111-R. We would like to thank S. Smith, J. Odenkirk, and T. Hampton for their editorial comments on the manuscript, and Fisheries Division Staff from the Virginia Department of Game and Inland Fisheries for conducting the field work that made this project possible.

## Literature Cited

Anderson, C. S. 1995. Measuring and correcting for size selection in electrofishing mark-recapture experiments. Transactions of the American Fisheries Society 124:663–676.

Bunt, C. M., S. J. Cooke, and D. P. Phillip. 2002. Mortality of riverine smallmouth bass related to tournament displacement and seasonal habitat use. Pages 545–552 *in* D. P. Phillip and M. S. Ridgway, editors. Black bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

Cross, D. G. and B. Stott. 1975. The effect of electrical fishing on the subsequent capture of fish. Journal of Fish Biology 7:349–357.

Dauwalter, D. C. and W. Fisher. 2007. Electrofishing capture probability of smallmouth bass in streams. North American Journal of Fisheries Management 27:162–171.

Dolan, C. R. and L. E. Miranda. 2003. Immobilization thresholds of electrofishing relative to fish size. Transactions of the American Fisheries Society 132:969–976.

Grabowski, T. B., T. D. Ferguson, J. T. Peterson, and C. A. Jennings. 2009. Capture probability and behavioral response of the robust redhorse, a cryptic riverine fish, to electrofishing. North American Journal of Fisheries Management 29:721–729.

Humston, R., B. M. Priest, W. C. Hamilton, and P. E. Bugas. 2009. Dispersal between tributary and main-stem rivers by juvenile smallmouth bass evaluated using otolith microchemistry. Transactions of the American Fisheries Society 139:171-19-84.

Lyons, J. and P. Kanehl. 2002. Seasonal movements of smallmouth bass in streams. Pages 149–160 *in* D. P. Phillip and M. S. Ridgway editors. Black bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

Margenau, T. L. 1987. Vulnerability of radio-tagged northern pike to angling. North American Journal of Fisheries Management 7:158–159.

Moore, S. E., B. L. Ridley, and G. L. Larson. 1983. Standing crops of brook trout concurrent with removal of rainbow trout from selected streams in Great Smokey Mountains National Park. North American Journal of Fisheries Management 3:72–80.

Odenkirk, J. S. and S. M. Smith. 2005. Single–versus multi-pass boat electrofishing for assessing smallmouth bass populations in Virginia rivers. North American Journal of Fisheries Management 25:717–724.

O'Neill, B. M. 2001. Market segmentation, motivations, attitudes, and preferences of Virginia resident freshwater anglers. Master's thesis. Virginia Polytechnic Institute and State University, Blacksburg.

Peterson, J. T., R. F. Thurow, and J. W. Guzevich. 2004. An evaluation of multipass electrofishing for estimating the abundance of stream-dwelling salmonids. Transactions of the American Fisheries Society133:462–475.

———, N. P. Banish, and R. F. Thurow. 2005. Are block nets necessary?: Movement of stream-dwelling salmonids in response to three common survey methods. North American Journal of Fisheries Management 25:732–743.

———, C. R. Jackson, C. P. Shea, and Guoyuan Li. 2009. Development and evaluation of a stream channel classification for estimating fish responses to changing streamflow. Transactions of the American Fisheries Society 138:1123–1137.

Peterson, N. P. and C. J. Cederholm. 1984. A comparison of the removal and mark-recapture methods of population estimation for juvenile coho salmon in a small stream. North American Journal of Fisheries Management 4:99–102.

Pine, W. E., K. H. Pollock, J. E. Hightower, T. J. Kwak, and J. A. Rice. 2003. A review of tagging methods for estimating fish population size and components of mortality. Fisheries 28:10–23.

Popoff, N. D. and R. M. Neumann. 2005. Range and movement of resident holdover and hatchery brown trout tagged with radio transmitters in the Farmington River, Connecticut. North American Journal of Fisheries Management 25:413–422.

Raibley, P. T., K. S. Irons, T. M. O'Hara, K. Douglas Blodgett, and R. E. Sparks. 1997. Winter habitats used by largemouth bass in the Illinois River, a large river floodplain ecosystem. North American Journal of Fisheries Management 17:401–412.

Reynolds, J. B. 1996. Electrofishing. Pages 221–253 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Riley, S. C. and K. D. Fausch. 1992. Underestimation of trout population size by maximum-likelihood removal estimates in small streams. North American Journal of Fisheries Management 12:768–776.

Rosenberger, A. E. and J. B. Dunham. 2005. Validation of abundance estimates from mark-recapture and removal techniques for rainbow trout captured by electrofishing in small streams. North American Journal of Fisheries Management 25:1395–1410.

Rowe, D. C., C. L. Pierce, and T. F. Wilton. 2009. Fish assemblage relationships with physical habitat in wadeable Iowa streams. North American Journal of Fisheries Management 29:1314–1332.

Sammons, S. M. and P. W. Bettoli. 1999. Spatial and temporal variation in electrofishing catch rates of three species of black bass (*Micropterus* spp.) from Normandy Reservoir, Tennessee. North American Journal of Fisheries Management 19:454–461.

Smith, P. P. and J. W. Kauffman. 1991. The effects of a slot size limit regulation on smallmouth bass in the Shenandoah River, Virginia. Pages 112–117 *in* D. C. Jackson, editor. Proceedings of the First International Smallmouth Bass Symposium. Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, Mississippi State.

Smith, S. M., J. S. Odenkirk, and S. J. Reeser. 2005. Smallmouth bass recruitment variability and its relation to stream discharge in three Virginia rivers. North American Journal of Fisheries Management 25:1112–1121.

Todd, B. L. and C. F. Rabeni. 1989. Movement and habitat use by stream-dwelling smallmouth bass. Transactions of the American Fisheries Society 118:229–242.

Van Arnum, C. G., G. L. Buynak, and J. R. Ross. 2004. Movement of smallmouth bass in Elkhorn Creek, Kentucky. North American Journal of Fisheries Management 24:311–315.

Van Den Avyle, M. J. and R. S. Hayward. 1999. Dynamics of exploited fish populations. Pages 127–166 *in* C. C. Kohler and W. A. Hubert, editors. Inland Fisheries Management in North America. American Fisheries Society, Bethesda, Maryland.

Van Deventer, J. S. and W. S. Platts. 1983. Sampling and estimating fish populations from streams. Transactions of the North American Wildlife and Natural Resources Conference, 48:349–354.

———. 1989. Microcomputer software system for generating population statistics for electrofishing data—Users Guide for MicroFish 3.0. USDA Forest Service, General Technical Report INT-254.

Venditti, D. A., D. W. Rondorf, and J. M. Kraut. 2000. Migratory behavior and forebay delay of radio-tagged juvenile fall Chinook salmon in a lower Snake River impoundment. North American Journal of Fisheries Management 20:41–52.

Young, S. P. and J. J. Isely. 2004. Temporal and special estimates of adult striped bass mortality from telemetry and transmitter return data. North American Journal of Fisheries Management 24:1112–1119.

Zehfuss, K. P., J. E. Hightower, and K. H. Pollock. 1999. Abundance of gulf sturgeon in the Apalachicola River, Florida. Transactions of the American Fisheries Society 128:130–143.