United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

General Technical Report **NC-159**

A Comparison of Four Electroshocking Procedures for Assessing the Abundance of Smallmouth Bass in Wisconsin Streams

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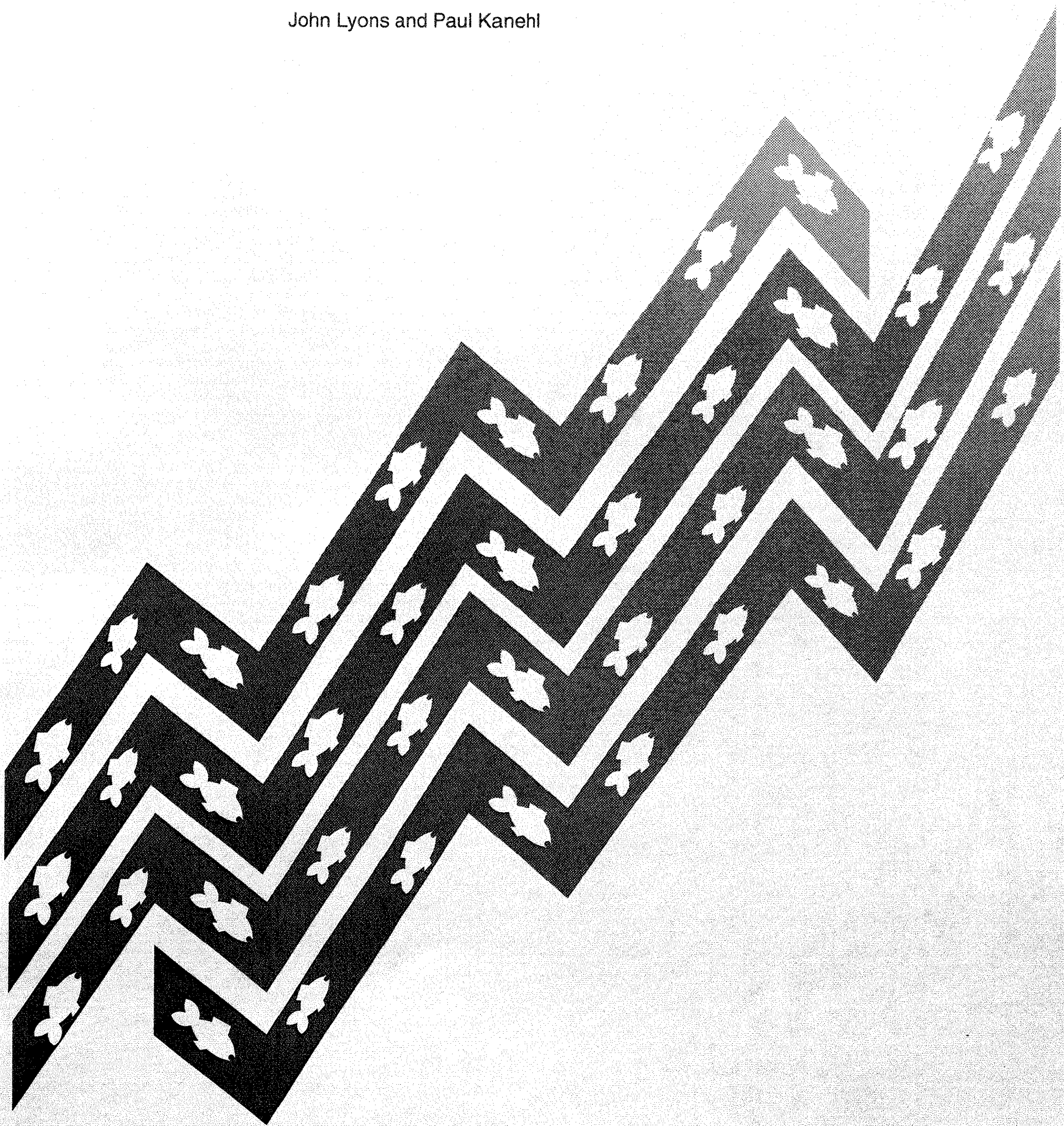

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication July 6, 1993
1993

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The Upper Midwest region of the United States contains many streams with smallmouth bass (*Micropterus dolomieu*) populations. Many of these streams provide excellent fishing opportunities (WDNR 1978, Holschlag 1990), but fisheries management of them is hampered by inadequate data on smallmouth bass population characteristics (Forbes 1985). Efforts to collect smallmouth bass population data have been impeded by an absence of standardized sampling procedures, coupled with the inherent difficulty of effectively sampling the types of streams where smallmouth bass live (Cleary and Greenbank 1954, Hendricks *et al.* 1980).

Since 1987, we have been sampling smallmouth bass streams throughout Wisconsin. One of our goals has been to develop effective procedures for collecting and interpreting smallmouth bass population data. In this paper, we compare results from four popular sampling approaches that involved sampling smallmouth bass with a "stream shocker" (also known as a "tow barge shocker"), a type of electroshocker widely used in Wisconsin and other States (Lazauski and Malvestuto 1990; Paul Seelbach, Michigan Department of Natural Resources, unpublished data). We provide guidelines based on our comparison for estimating the abundance of smallmouth bass in streams shallow enough to sample by wading.

In the process of examining sampling procedures, we have generated a substantial data base on smallmouth bass abundance and size structure in Wisconsin streams. We present and briefly discuss the data base in this paper.

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We hope that the sampling guidelines presented here will be used by biologists in Wisconsin and surrounding States to expand and improve the data base. A larger data base will lead to a better understanding of smallmouth bass population dynamics, and better management of smallmouth bass fisheries in streams of the Upper Midwest.

METHODS

Sampling Sites

From 1987 through 1992, we sampled many streams throughout Wisconsin (fig. 1) that represented a broad range of habitat types and sampling conditions. In this paper, we present and discuss data from only those streams where we actually caught smallmouth bass or where smallmouth bass were known to have occurred within the last 15 years. Many of our sampling sites were located on streams reputed to have the best smallmouth bass fisheries in a particular region of the State (Forbes 1985, Holschlag 1990). Sites were on third- to fifth-order streams, and had drainage areas of 26 to 1826 km^2. Site lengths ranged from 200 to 1900 m, but most were between 800 and 1200 m, which exceeded the normal summer home range of smallmouth bass (Gerking 1953, Todd and Rabeni 1989). Sites consisted of at least two (usually four or more) complete riffle-pool sequences. Mean widths ranged from 4.4 to 42.7 m. All sites were shallow enough to effectively sample by wading, although some had pool areas that were too deep to wade. Mean depths of sites were always less than 1 m; maximum pool depths ranged from 0.5 to 3.2 m.

General Sampling Procedures

To collect smallmouth bass, we used a standard Wisconsin Department of Natural Resources (WDNR) direct current (DC) "stream shocker"

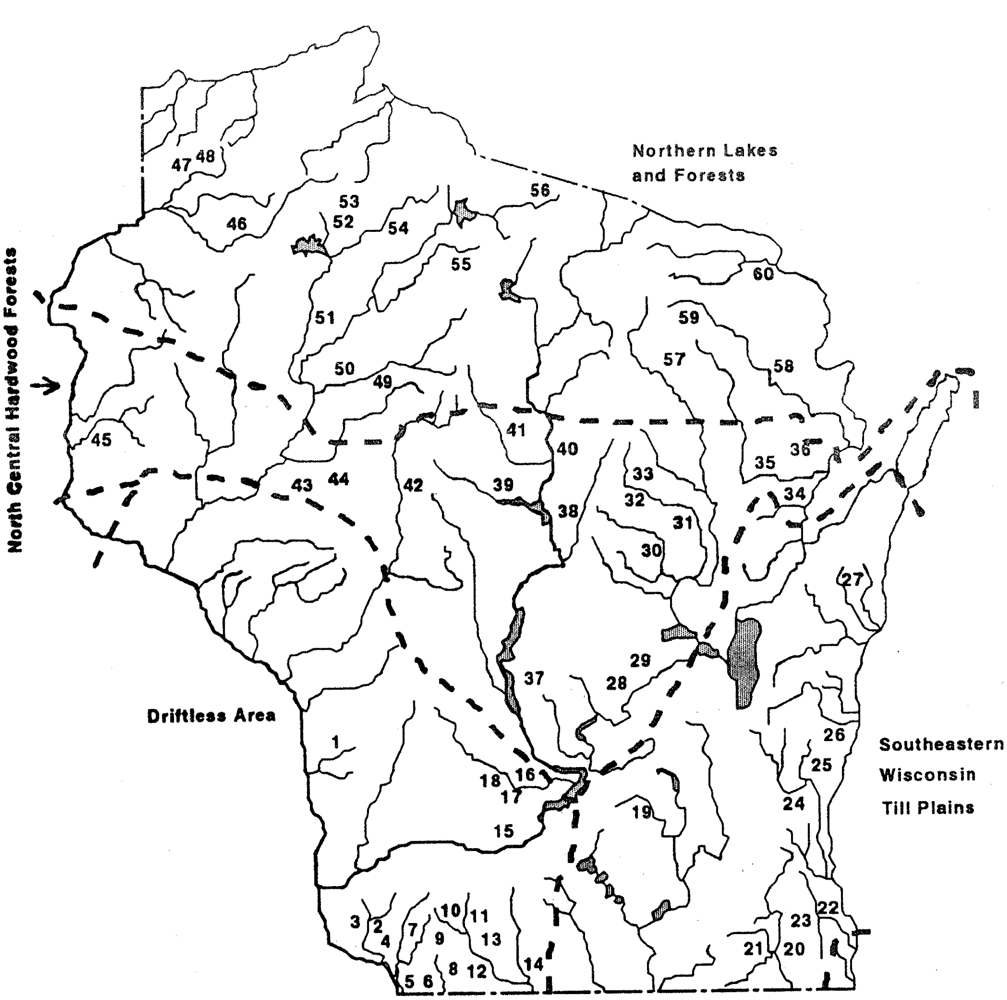

Figure 1.—*Map of Wisconsin showing locations of streams sampled (numbers refer to stream name codes in the Appendix) and ecoregion boundaries.*

(Novotny and Priegel 1971). At a few sites with deep pools, we also used a boat-mounted "mini-boom shocker" (Novotny and Priegel 1974, Reynolds 1983) together with stream shockers during removal sampling (see below). The stream shocker consisted of a 2500-watt alternating current (AC) generator and associated electronics mounted in a small shallow-draft boat (the tow barge) that the three operators pulled behind them as they waded upstream. Output from the generator went to a control box where it was converted to DC by a rectifier. From the control box, DC output passed into the water through three anodes, held by the operators. Two of these anodes were attached to the control box by long insulated wires that allowed the operators to move up to 8 m away from the boat. Current from the anodes passed through the water and returned to the generator via a metal cathode mounted on the bottom of the boat, thus completing the electrical circuit. The operators used dip nets to capture fish that were stunned by the stream shocker, and then placed these fish in a holding tank in the boat until they recovered and could be processed. Following the guidelines of Novotny and Priegel (1971), the operators adjusted DC output and anode size to optimize shocker effectiveness at the observed water conductivity at the sampling site. Typically, DC output ranged from 3 to 7 amperes and from 100 to 250 volts.

We sampled only during daylight mostly between May and September. Because wading a stream in the dark while towing a stream shocker was difficult and potentially dangerous, we did not attempt night sampling, even though Paragamian (1989) reported that mini-boom electroshocking for smallmouth bass was more effective at night than during the day. We sampled only when streams were at or below normal baseflow. At two sites in southwestern Wisconsin, on the Little Platte River and Mineral Point Branch, we sampled regularly throughout the ice-free periods of 1990 and 1991.

During sampling, we tried to capture all smallmouth bass observed. We measured (total length; TL) and weighed (either individually or in aggregate) all captured smallmouth bass. At most sites, we collected scales from a subsample of smallmouth bass to determine age. After processing, we returned surviving smallmouth bass to the water near where they had been captured. If we planned additional sampling at the site, we marked smallmouth bass with a fin clip or a numbered t-bar tag for future identification before we released them.

The smallmouth bass data in this paper came from 90 sites on 60 streams sampled from 1987 through 1992. We sampled many of these sites more than once, for a total of 189 discrete sampling events (Appendix). In all 189 sampling events, we collected a **catch-per-unit-effort (CPUE) sample**, results of which form most of our data base. During some of the 189 sampling events, we also collected a **recapture sample** (18 events), a **multiple-shocker sample** (10 events), or a **removal sample** (6 events).

CPUE Sampling

The CPUE sample consisted of a single upstream pass with one stream shocker over the entire length of the site. We did not use block nets (which prevent fish movement into or out of the site) during CPUE sampling. The length of stream that we sampled was our measure of effort. One stream shocker covered a region up to 16 m wide, so we could not sample all of the stream channel at sites wider than this.

We estimated the sampling error associated with CPUE sampling through a one-way analysis of variance (ANOVA; SAS 1988) of catch data from eight sites in southwestern Wisconsin where CPUE samples were collected twice during the same summer (15 total site and year combinations). Only samples collected at least 6 weeks apart were used in this analysis to avoid possible biases associated with repeated sampling over short time intervals (see discussion of recapture sampling results). Site was our class variable in the ANOVA. We determined the mean CPUE, by size group, for all samples used in the ANOVA, and then multiplied the root mean square error value from the ANOVA by the appropriate probability point of a *t* distribution (2.145) to generate a 95 percent confidence interval for the mean. The size of the confidence interval relative to the mean provided an estimate of the variation in CPUE due to sampling error. This confidence interval probably overestimated sampling error because some of the variation in CPUE within each site was almost certainly due to variation in smallmouth bass abundance rather than variation in sampling effectiveness.

We used the data from the CPUE sampling to make broad comparisons of smallmouth bass populations among different regions of Wisconsin. Because some regions of the State received relatively little sampling, these analyses were limited and conclusions drawn from them should be considered preliminary. We used Omernik's ecoregions, which are broad landscape areas distinguished from each other by land surface form, soils, potential natural vegetation, and land use (Omernik 1987), to make regional comparisons. Most of Wisconsin falls within four ecoregions: the Driftless Area, the Southeastern Wisconsin Till Plains, the North Central Hardwood Forests, or the Northern Lakes and Forests (fig. 1). Stream fish assemblages and habitat characteristics differ among these four ecoregions (Lyons 1989).

Recapture Sampling

The recapture sample consisted of a second upstream shocking pass over the entire length of the site, carried out 1 or 2 days after the CPUE sample. As in the CPUE sample, no block nets were used. We used one stream shocker in 12 recapture sampling events, two stream shockers together in five events, and three stream shockers together for one event. The objective of the recapture sample was to determine the ratio of marked to unmarked bass present at the site as a result of the CPUE sample. We used this ratio in the Chapman modification of the Petersen mark-recapture formula (Ricker 1975) to estimate smallmouth bass population size at the site. To avoid bias, we made population estimates only when the following three conditions were met (derived from Ricker 1975):

1) At least 20 smallmouth bass were marked immediately before the recapture sample;
2) At least 5 of these marked smallmouth bass were recaptured;
3) At least 15 percent of the total number of smallmouth bass captured during the recapture run consisted of marked fish.

During many CPUE samples, we were unable to mark at least 20 smallmouth bass, and for these sampling events we did not attempt a recapture sample. Of the 18 recapture samples that we did make, 5 samples did not meet conditions 2 or 3, and we did not make population estimates for these samples.

Multiple-Shocker Sampling

The multiple-shocker sample consisted of a second upstream pass over the entire length of the site with two or three stream shockers used together. The catch from all shockers was pooled to provide an index of smallmouth bass abundance. Multiple-shocker sampling took place 1 or 2 days after CPUE sampling, and no block nets were used. Of the 10 multiple-shocker samples, 6 also served as recaptures samples. The goal of multiple-shocker sampling was to determine how much the catch of smallmouth bass increased with a doubling or tripling of electroshocking effort. With one exception, we made multiple-shocker samples only at wide sites (> 20 m mean width), where one stream shocker could not cover the entire stream channel, but two or three stream shockers together could.

Removal Sampling

The removal sample (also known as a depletion sample) differed from other types of sampling in several important respects. First, in a removal sample, we shocked only 50- to 200-m-long segments of the site. Second, during shocking, fish were prevented from entering or leaving the segment by small-mesh block nets at the upstream and downstream boundaries of the segment. Third, to conduct the sample, we made three to five upstream shocking passes (the number of passes depended on the rate at which the catch rate of smallmouth bass declined) over the length of the segment. Smallmouth bass captured during each pass were held and processed separately. Fourth, we used three stream shockers together (or in a few instances two stream shockers and a mini-boom shocker) during each pass. The goal was to catch as many smallmouth bass as possible in each pass, so we tried to maximize capture efficiency by using multiple shockers.

The objective of the removal sample was to progressively reduce the number of smallmouth bass within the segment by removing all smallmouth bass caught during each pass. The relationship between the number of smallmouth bass removed and the decline in catch over a series of passes could then be used to estimate smallmouth bass population size within the segment. Various mathematical estimators are available for determining population size based on removal sample data, each with different data requirements, underlying assumptions, and potential biases (Ricker 1975). We used the maximum likelihood estimator under the generalized removal model (Otis *et al.* 1978) of the computer program CAPTURE (White *et al.* 1982) to generate population estimates for each segment, and then summed these estimates to estimate population size at the site. The generalized removal model did not assume equal catchabilities among passes when at least four passes were made; the number of different catchability estimates generated by the model was equal to the number of passes minus two. To avoid bias, we calculated population size for a segment only when estimated catchability of smallmouth bass in each removal pass was at least 30 percent. During the six removal samples, estimated catchabilities were always above 40 percent and usually above 60 percent, so we were able to calculate population estimates for all the samples.

Comparison of Sampling Procedures

To compare procedures, we converted smallmouth bass abundance (either actual total catch or estimated population size) to number per 100 m of stream length sampled. Several different size and age classes of smallmouth bass were analyzed separately; all analyses were conducted using the SAS computer package (SAS 1988).

Young-of-the-year (YOY) smallmouth bass were analyzed apart from older smallmouth bass because: (1) YOY smallmouth bass are usually not fully vulnerable to capture until late July (Forbes 1985, 1989; WDNR unpublished data) and much of our sampling took place before late July; (2) sampling efficiency for YOY smallmouth bass tends to be lower than for older smallmouth bass (Bayley and Dowling 1990); and (3) the abundance of YOY smallmouth bass varies much more from year to year than that of older smallmouth bass (Cleary 1956; Paragamian 1984a, 1984b; Forbes 1985, 1989; Mason *et al.* 1991). Because YOY smallmouth bass could easily be killed by repeated electroshocking, handling, and marking, we did not include them in mark-recapture, multiple shocker, and removal sampling.

For older smallmouth bass, we considered a nested series of three age and size groups—age I and older, greater than 203 mm (8 inches) TL, and greater than 354 mm (14 inches) TL—when examining data from the CPUE and multiple shocker samples. Age I smallmouth bass ranged from about 80 to 150 mm during our sampling. Catches of smallmouth bass > 203 mm TL were too small to allow a size breakdown for mark-recapture and removal samples. Before 1989, there had been no length limit on harvest in Wisconsin, and 203 mm TL was the approximate size at which many anglers began to keep smallmouth bass and at which males began to become sexually mature (Forbes 1989, WDNR unpublished data). In 1989, a 355-mm TL minimum length limit for smallmouth bass harvested was enacted on all waters in the southern two-thirds of Wisconsin, and a 305-mm (12-inch) TL minimum length limit was enacted on all waters in the northern one-third of the State.

We judged and compared the effectiveness of all four sampling procedures using two criteria: (1) the accuracy and precision of the information produced by the procedure, and (2) the amount of time and labor required to obtain the information. These criteria, although partially based on quantitative data, were largely subjective. Based on our comparison, we developed guidelines and recommendations for estimating the abundance and size structure of smallmouth bass in "wadeable" streams. In making our recommendations, we tried to recognize that most fish managers have limited time and staffing available for stream surveys.

CPUE SAMPLING

Results

Catches of smallmouth bass per 100 m of stream length differed greatly among sites during CPUE sampling but were generally small (table 1 and Appendix). For smallmouth bass ≥ age I, catches ranged from 0.0 to 60.8, with 98 percent of the 189 samples below 20.0 and 89 percent below 10.0. The median CPUE for all samples was only 1.6. For smallmouth bass > 203 mm TL, CPUE ranged from 0.0 to 24.4, with over 99 percent below 10.0 and 89 percent below 5.0. The median catch was only 0.7. For smallmouth bass > 355 mm TL, CPUE was particularly low, ranging from 0.0 to 2.6, with a median of 0.0 and only 8 percent of samples greater than 0.3. Catch per unit effort of YOY smallmouth bass was more variable than that for older smallmouth bass. For the 93 CPUE samples (40 streams) collected between late July and mid-November, the period when YOY smallmouth bass were fully vulnerable to capture, catches ranged from 0.0 to 110.2, with 89 percent of samples below 10.0, and a median value of 1.8.

Only a handful of sites, almost all in southern Wisconsin, had particularly large catches. The maximum CPUE for all four age and size groups of smallmouth bass occurred in the Sheboygan River. Probably few people fished this site, which had good habitat but difficult public access. Smallmouth bass here contained high concentrations of PCB's, and a public health advisory had been issued warning people not to eat them (WDNR 1992).

Sites with relatively large catches (≥ 10) for smallmouth bass ≥ age I were on:

Sheboygan R. (mile 7.6)	24 September 1991	CPUE = 60.8
Milwaukee R. (mile 66.6)	11 June 1991	47.8
Milwaukee R. (mile 66.6)	5 June 1992	21.9
Milwaukee R. (mile 65.2)	11 June 1991	12.2
Milwaukee R. (mile 65.2)	2 June 1992	18.2
Milwaukee R. (mile 53.1)	26 August 1991	12.5
N. Fk. Bad Axe R. (mile 12.7)	1 September 1992	20.3
Galena R. (mile 29.8)	1 September 1992	18.3
Mineral Point Br. (mile 12.3)	29 August 1989	18.0
Mineral Point Br. (mile 12.3)	3 July 1992	13.4
Mineral Point Br. (mile 12.3)	3 September 1992	13.9
Little Platte R. (mile 19.1)	7 July 1989	10.0
Little Platte R. (mile 19.1)	12 September 1990	13.9
Little Platte R. (mile 19.1)	1 July 1992	10.8
Pigeon Cr. (mile 1.6)	16 July 1991	12.0
Pigeon Cr. (mile 1.6)	28 August 1990	13.0
Pigeon Cr. (mile 1.6)	10 July 1992	15.5
Pigeon Cr. (mile 1.6)	24 August 1992	11.4
Ames Br. (mile 4.1)	26 August 1992	11.9

Relatively large catches (≥7.5) of smallmouth bass > 203 mm TL occurred in:

Sheboygan R. (mile 7.6)	24 September 1991	CPUE = 24.4
Pigeon Cr. (mile 1.6)	16 July 1991	8.0
Pigeon Cr. (mile 1.6)	28 August 1991	9.5
Little Platte R. (mile 19.1)	12 September 1990	8.0
Galena R. (mile 29.8)	7 September 1990	7.5

Only three sites had a CPUE greater than 1.0 for smallmouth bass > 354 mm TL:

Sheboygan R. (mile 7.6)	24 September 1991	CPUE = 2.6
Galena R. (mile 29.8)	7 September 1990	1.4
Galena R. (mile 29.8)	26 August 1991	1.1
Galena R. (mile 29.8)	1 September 1992	2.3
Little Platte R. (mile 19.1)	18 August 1992	1.1

For YOY smallmouth bass, a CPUE greater than 10 occurred in:

Sheboygan R. (mile 7.6)	24 September 1991	CPUE = 110.2
Mineral Point Br. (mile 12.3)	30 August 1989	33.4
Mineral Point Br. (mile 12.3)	27 August 1991	39.2
Mineral Point Br. (mile 12.3)	3 September 1992	16.1
Little Platte R. (mile 19.1)	7 September 1989	28.4
Pigeon Cr. (mile 1.6)	28 August 1991	25.5
Pigeon Cr. (mile 1.6)	24 August 1992	16.4
Little Wolf R. (mile 9.7)	8 August 1988	19.4
Rattlesnake Cr. (mile 4.4)	5 September 1991	13.8
Big Rib R. (mile 16.3)	7 August 1987	13.1

Generally, smallmouth bass CPUE was higher in the two southern Wisconsin ecoregions, the Driftless Area (DRT) and the Southeastern Wisconsin Till Plains (SEP), than in the two northern Wisconsin ecoregions, the North Central Hardwoods Forest (CHF) and the Northern Lakes and Forests (NLF). The DRT and SEP ecoregions had higher median and maximum CPUE values than the CHF and NLF ecoregions for all smallmouth bass age and size groups except YOY (table 1). The CHF had the highest median CPUE for YOY smallmouth bass (5.5), but the maximum value for the CHF (19.4) was much lower than those for the DRT (39.2) and the SEP (110.2). The SEP had the highest maximum CPUE for all smallmouth bass age and size groups (all from the Sheboygan River), and the DRT had the highest median CPUE except for YOY. The NLF had the lowest median and maximum CPUE for all smallmouth bass age and size groups. The DRT was the only ecoregion with a median CPUE above zero for smallmouth bass > 354 mm TL. Smallmouth bass in this size group were particularly scarce in the CHF and NLF ecoregions; only five were captured during CPUE sampling in the CHF, and two were captured in the NLF.

The sampling error associated with CPUE data was relatively high (table 2). For smallmouth bass ≥ age I, the estimated 95-percent confidence interval for sampling error was ± 55 percent of the overall mean CPUE (7.5). In other words, to have a better than 95 percent chance that a difference between two CPUE samples was not merely the result of sampling error, the difference would have to be greater than 55 percent of the mean value of the two samples. For smallmouth bass > 203 mm TL, the 95 percent confidence interval was ± 64 percent of the mean CPUE (4.2). For smallmouth bass > 354 mm TL, the mean CPUE was very low (0.27), resulting in a 95 percent confidence interval that was large when expressed as a proportion of the mean—± 204 percent—but relatively small when expressed as actual catch per 100 m—± 0.55.

Table 1.—*Summary statistics for smallmouth bass CPUE sampling, by ecoregion*

Ecoregion	Number[1] of: Streams	Number[1] of: Events	Median catch per 100 m by age/size group (Range given in parentheses): YOY	≥ Age I	>203 mm	>354 mm
Driftless Area (DRT)	18/14	101/55	1.0 (0.0-39.2)	3.6 (0.0-20.3)	2.2 (0.0-9.5)	0.1 (0.0-2.3)
Southeastern Wisconsin Till Plains (SEP)	9/5	36/6	1.7 (0.0-110.2)	1.3 (0.0-60.8)	0.5 (0.0-24.4)	0.0 (0.0-2.6)
North Central Hardwood Forests (CHF)	18/12	27/19	5.5 (0.0-19.4)	0.8 (0.0-4.0)	0.3 (0.0-2.0)	0.0 (0.0-0.3)
Northern Lakes and Forests (NLF)	15/9	25/13	0.7 (0.0-6.9)	0.4 (0.0-1.9)	0.2 (0.0-1.5)	0.0 (0.0-0.2)
Totals	60/40	189/93	1.8 (0.0-110.2)	1.6 (0.0-60.8)	0.7 (0.0-24.4)	0.0 (0.0-2.6)

[1] *The first number is the total number of streams sampled or sampling events; the second is the number of streams sampled or sampling events between late July and November, when young of year (YOY) were vulnerable to capture.*

Table 2.—*Catch data from pairs of CPUE samples collected at the same sites during the same year, used in a one-way ANOVA to estimate the sampling error associated with CPUE sampling*

		Catch per 100 m by age/size group and time period					
		≥ Age I		>203 mm		>354 mm	
Stream (Mile[1])	Year	June July	August Sept.	June July	August Sept.	June July	August Sept.
Pigeon Cr. (1.6)	1991	12.0	13.0	9.5	8.0	1.0	0.0
Pigeon Cr. (1.6)	1992	15.5	11.4	5.9	4.1	.5	.0
Pigeon Cr. (6.7)	1991	2.8	3.2	2.0	2.4	.0	.0
Little Platte R. (19.1)	1989	10.0	9.8	4.8	4.1	.5	.2
Little Platte R. (19.1)	1990	8.6	13.9	3.2	6.0	.3	.2
Little Platte R. (19.1)	1991	6.6	13.3	3.3	8.1	.1	.3
Little Platte R. (19.1)	1992	10.8	9.8	6.0	7.3	.5	1.1
Galena R. (29.8)	1991	3.9	6.2	3.8	5.8	1.0	1.1
Mineral Point Br. (12.3)	1991	7.7	6.9	2.5	3.3	.2	.1
Mineral Point Br. (12.3)	1992	13.4	13.9	3.4	3.7	.1	.2
Ames Br. (4.1)	1991	4.1	5.7	4.1	5.5	.2	.2
Otter Cr. (3.8)	1990	1.0	1.6	.4	.0	.0	.0
Otter Cr. (3.8)	1991	3.0	3.2	3.0	2.6	.2	.0
Otter Cr. (6.8)	1990	1.2	1.5	1.0	.7	.1	.0
Otter Cr. (6.8)	1991	5.7	5.3	5.5	5.2	.0	.0
Unweighted mean, pooled by time period		7.5		4.2		0.27	
95% confidence interval:							
Original data		± 4.1		± 2.7		± 0.55	
As a percent		55		64		204	

[1] *In this and subsequent tables, "Mile" indicates location of the site. "Mile" is the distance in miles (following the stream channel) between the downstream end of the site and the mouth of the stream.*

Seasonal variations in smallmouth bass CPUE were substantial in the Little Platte River and Mineral Point Branch, the two streams sampled outside of the late spring and summer. These streams, although only 25 km apart, had very different annual patterns in CPUE (fig. 2). In the Little Platte River, CPUE was relatively high between May and September but very low between November and March, both for smallmouth bass ≥ age I and > 203 mm TL. Peak catches occurred in late summer. Conversely, in Mineral Point Branch, CPUE for both groups remained relatively high throughout the sampling period. In 1990 the highest CPUE occurred in November. In both streams, CPUE of smallmouth bass > 354 mm TL was always low, but generally showed the same seasonal patterns as the CPUE of the other two age/size groups (Appendix).

Major floods appeared to cause a temporary reduction in CPUE of smallmouth bass. In early July 1990, a series of large thunderstorms led to heavy flooding in many southwestern Wisconsin streams, including the Little Platte River and Mineral Point Branch (personal observations). We conducted CPUE sampling in both streams less than a week after this flooding had subsided, and at both sites we had catches well below those before the flooding (fig. 2). However, when we sampled the sites again approximately 2 months after the flood, CPUE was similar to or higher than pre-flood values.

The amount of time and effort required to complete a CPUE sample varied depending on the size and accessibility of the stream, the length of the sampling site, and the number of bass captured. Generally, however, a 1200-m-long site could be sampled in 3 to 6 hours.

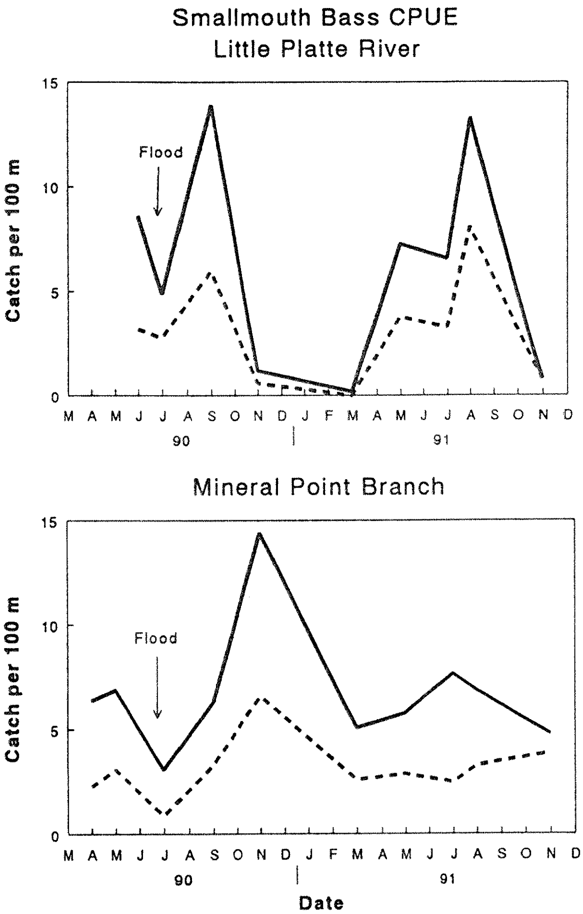

Figure 2.—*Plots of catch per 100 m for two smallmouth bass size groups during 1990 and 1991 CPUE sampling of the Little Platte River (Mile 19.1) and Mineral Point Branch (Mile 12.3). The solid line is for all sizes of smallmouth bass (excluding YOY), and the dashed line is for smallmouth bass greater than 203 mm total length.*

Three people were required to conduct CPUE sampling, and additional people did not substantially reduce sampling time unless many bass had to be processed. Thus, the total labor required to conduct a typical CPUE sample ranged from 9 to 18 person-hours.

Discussion

For CPUE sampling to provide an accurate index of smallmouth bass abundance, the catch of smallmouth bass during a sample must be directly proportional to the number of smallmouth bass present at the site. However, factors other than smallmouth bass population size may influence how many smallmouth bass are caught during CPUE sampling and thus obscure any relationship between CPUE and population size. Based on our experiences in the field, we are convinced that the experience of the sampling crew, the operating performance of the electroshocker, the water conditions during the sampling (e.g., water levels, conductivity, turbidity, temperature), and the physical characteristics of the site (e.g., types of habitat present, size of stream, depth of pools, amount of cover) can all influence the capture efficiency of the stream shocker. To minimize crew and shocker effects, we always conducted CPUE sampling with a well-trained and experienced crew and a properly functioning stream shocker that had output within a range proven effective for capturing smallmouth bass (Novotny and Priegel 1971). For our data, we believe that crew and shocker effects on smallmouth bass catch were relatively minor. However, results of our sampling error analysis suggest that other factors, including water conditions and site characteristics, may have substantially influenced catch rates.

Data collected by Bayley and Dowling (1990) on the capture efficiency of the electric seine and the backpack shocker, two other types of apparatus designed to sample smallmouth bass in wadeable streams, provide insight into the influence of environmental factors on smallmouth bass catch during CPUE sampling. At 61 sites in central Illinois, Bayley and Dowling (1990) determined the capture efficiencies of a 9.3-m-long AC electric seine (Bayley *et al.* 1989, Angermeier *et al.* 1991) and a pulsed DC backpack electroshocker (Reynolds 1983) for smallmouth bass and other *Micropterus* species. They estimated the importance of percent riffles, water velocity, visual impedence (an index combining turbidity, water depth, and amounts of submerged and bank vegetation), physical impedence (a qualitative index of the degree to which large snags, deep pools, or overhanging vegetation interfered with sampling), conductivity, and water temperature in influencing variation in capture efficiency. They found that only water velocity and conductivity had a significant effect, and then only for the electric seine. However, most of their variation in sampling effectiveness remained unexplained. Capture efficiency decreased with increasing mean water velocity and conductivity. The range of mean water velocities (0.0-0.35 m/sec) encountered by Bayley and Dowling (1990) overlapped completely with the range we encountered in Wisconsin. However, their range of conductivities (431-1210 uS) overlapped only partially with ours (69-781 uS), and all our conductivity values from the northern half of Wisconsin were lower than their lowest value. Other studies have shown that for waters with conductivities below 200 uS, electroshocking efficiency improves with increasing conductivity (Novotny and Priegel 1971, Reynolds 1983, Cowx 1990).

Variation in capture efficiency among streams may have contributed to the observed differences in CPUE between northern and southern ecoregions. Most sampling sites in the NLF had conductivities less than 200 uS, and thus capture efficiencies may have been lower there than in the other three ecoregions, where conductivities were almost always above 200 uS. Smallmouth bass in southern Wisconsin occurred in smaller streams than in northern Wisconsin, and sampling sites in the NLF and CHF tended to be wider and deeper and thus generally more difficult to sample effectively than those in the DRT and SEP.

Our results indicate that smallmouth bass abundance may fluctuate dramatically over the course of a year in a Wisconsin stream. We believe that the temporal changes in CPUE that we observed in the Little Platte River were caused by seasonal movements of smallmouth bass. In the Embarrass/Wolf River system in northeastern Wisconsin, smallmouth bass were observed to migrate long distances (35-109 km) to winter habitat (Langhurst and Schoenike 1990). A radio-tracking study in Otter Creek, located about 40 km east of the Little Platte River site, indicated a similar although shorter (2-15 km) migration in the fall to relatively deep ($\geq$ 1.3 m), slow-moving pools and runs (WDNR unpublished data). Pools and runs deeper than 1.3 m were scarce at the Little Platte River site, and we believe that most smallmouth bass left there in the fall to find suitable winter habitat. Many of these smallmouth bass returned to the site in the spring; several smallmouth bass were recaptured in 1991 that had been tagged in 1990. We do not know why large numbers of smallmouth bass remained through the winter at the Mineral Point Branch site, which also lacked pools and runs deeper than 1.3 m.

Recommendations

We believe that with a well-trained and experienced crew, a properly functioning stream shocker, and sampling and site conditions that are not extreme or unusual, CPUE sampling can provide a reasonably accurate index of smallmouth bass abundance in Wisconsin streams. We recommend using CPUE sampling to track trends in abundance at a particular site or to compare abundances among sites with similar environmental characteristics. However, we recommend against using CPUE results to compare smallmouth bass abundances among sites that differ substantially in conductivity, water velocity, width, depth, water clarity, or other physical and chemical conditions. Our field experiences, coupled with the work of Bayley and Dowling (1990), suggest that differences in sampling efficiency caused by differences in environmental characteristics can result in major differences in smallmouth bass CPUE. To improve the utility of CPUE sampling for intersite comparisons, we recommend that a study be undertaken to quantify relationships between various environmental characteristics and stream-shocker sampling efficiency.

Although we believe that CPUE sampling is accurate, our sampling error analysis indicates that it is fairly imprecise. As a conservative rule of thumb, a difference in catch rate between two CPUE samples should not be considered biologically meaningful unless it is more than 60 percent of the mean of the two samples or more than 0.6 smallmouth bass per 100 m, whichever is larger.

We recommend conducting CPUE sampling between mid-July and mid-September. Our results from the Little Platte River, as well as those from the Embarrass River (Langhurst and Schoenike 1990) and Otter Creek (WDNR unpublished data), demonstrate that fall, winter, or early spring CPUE sampling is likely to greatly underestimate the number of smallmouth bass present in many Wisconsin streams during the summer. Sampling during late spring will probably yield a fairly accurate index of smallmouth bass summer populations, but the process of sampling may disrupt smallmouth bass spawning and nest defense within the study area. If this is not a concern (e.g., the study area is small relative to the length of stream inhabited by smallmouth bass, or the number of smallmouth bass likely to be disturbed by sampling is small), or if the goal of sampling is to estimate characteristics of the spawning population, then sampling in late May or June is acceptable. Note, however, that there is evidence that some large adult smallmouth bass migrate into small tributaries during the spring to spawn, and then return downstream to their summer habitat in larger streams (Forbes 1989). Results from late spring may thus not reflect the true summer abundance of large smallmouth bass. Sampling Wisconsin streams after mid-July avoids the problems associated with seasonal smallmouth bass movements and also allows estimation of the relative abundance of YOY smallmouth bass.

We do not recommend conducting CPUE sampling soon after flooding at a site because catches may underestimate typical smallmouth bass abundances. However, we are still uncertain about how soon after flooding it is safe to undertake CPUE sampling; tentatively, we suggest not sampling for at least 2 weeks after the end of a major flood (i.e., a high flow event with a recurrence interval of more than 2 years) and at least 1 week after a smaller flood.

RECAPTURE SAMPLING

Results

We collected 18 recapture samples, but had sufficient recaptures for only 13 mark-recapture population estimates (table 3). These 13 population estimates ranged from 5.2 to 30.6 per 100 m for smallmouth bass ≥ age I. The median estimate was 11.2. Four of the 13 estimates (31 percent) were more than 20.0; the largest value (30.6) occurred in the North Fork of the Bad Axe River (Mile 12.7) during July 1991. Mark-recapture population estimates were positively correlated with catches during CPUE sampling (Spearman Rank Correlation = 0.52, $p = 0.07$; fig. 3).

For most of the recapture samples, the number of smallmouth bass caught during the recapture run was less than the number caught during the marking run. Of the 12 samples for which one shocker was used for both the marking and recapture runs, 10 had lower catches during the recapture run (table 4). This number of occurrences was significantly more than expected by chance (sign test; $p = 0.0193$). If each of the 12 samples was treated as an independent observation, a paired t-test of the catch in the marking run versus the catch in the recapture run indicated that catch in the recapture run was significantly lower ($t = 4.97$; $p = 0.0004$; catch data log transformed to approximate normality). For all 12 samples, the median value of the ratio of catch in the recapture run to catch in the marking run was 0.66; the range was 0.58 to 1.22.

Mark-recapture population estimates required twice the time and effort of CPUE samples because they involved two samplings of the site. Thus, at a site 1200 m long, 18 to 36 person-hours of work were normally required to collect the data for a mark-recapture estimate.

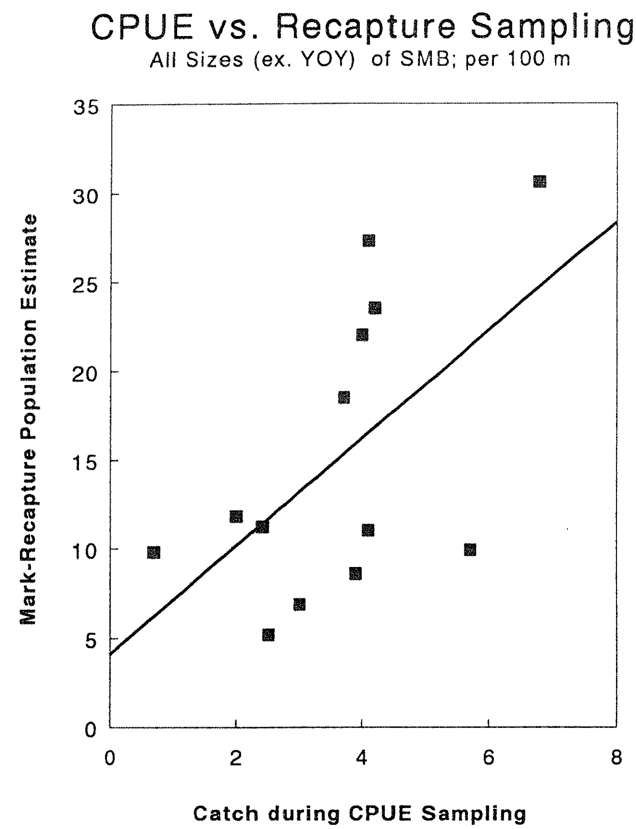

Figure 3.—*Plot of catch per 100 m during CPUE sampling versus estimated population size per 100 m based on recapture sampling for 13 Sampling events.*

Table 3.—*Mark-recapture population estimates of smallmouth bass ≥ age I*

Stream (mile)	Time period	Site length m	Mean width m	Population estimate and 95% confidence interval number per 100 m
North Fork Bad Axe R. (8.1)	July 88	1200	8.3	5.2 3.3 - 8.8
North Fork Bad Axe R. (12.7)	July 91	1000	14.2	30.6 20.7 - 47.1
Rattlesnake Cr. (4.4)	June 87	1300	9.1	23.5 17.3 - 32.8
Little Platte R. (19.1)	June 87	1200	16.5	11.8 4.8 - 29.5
Galena R. (29.8)	July 87	1900	14.0	Insufficient recaptures
Galena R. (29.8)	July 91	1900	17.9	8.6 5.0 - 15.8
Mineral Point Branch (12.3)	July 87	1200	7.0	18.5 10.9 - 33.3
Ames Branch (4.1)	July 91	1200	7.3	11.0 7.9 - 15.8
Otter Cr. (0.4)	July 91	1200	9.0	11.2 7.2 - 18.1
Otter Cr. (3.8)	July 91	1200	8.8	6.9 4.3 - 11.9
Otter Cr. (6.8)	July 91	1300	8.6	9.9 7.1 - 14.5
Milwaukee R.[1] (64.4)	June 89	1200	27.0	27.3 16.9 - 46.5
Milwaukee R.[1] (64.4)	June 90	1200	26.7	Insufficient recaptures
Milwaukee R.[1] (64.4)	June 91	1200	23.7	22.0 13.4 - 39.0
Big Roche a Cri Cr. (1.6)	July 88	1200	12.9	Insufficient recaptures
Embarrass R.[1] (46.4)	Aug. 88	1300	27.5	Insufficient recaptures
West Fork[2] Chippewa R. (14.5)	Aug. 89	1200	27.6	9.8 3.6 - 24.5
East Fork[1] Chippewa R. (23.7)	Aug. 89	1150	30.8	Insufficient recaptures

[1] *Two stream shockers used during recapture run.*
[2] *Three stream shockers used during recapture run.*

Table 4.—*Comparison of smallmouth bass catches (≥ age I) in marking and recapture runs for several studies involving a single stream shocker*

Stream (mile or station)	Time period	Smallmouth bass catch: Marking run	Smallmouth bass catch: Recapture run	Ratio
Data from this study:				
North Fork Bad Axe R. (8.1)	July 88	36	26	0.72
North Fork Bad Axe R. (12.7)	July 88	107	67	.63
Rattlesnake Cr. (4.4)	June 87	110	86	.78
Little Platte R. (19.1)	June 87	26	17	.65
Galena R. (29.8)	July 87	65	79	1.22
Galena R. (29.8)	July 91	74	47	.64
Mineral Point Branch (12.3)	July 87	66	42	.64
Ames Branch (4.1)	July 91	65	67	1.03
Otter Cr. (0.4)	July 91	61	40	.66
Otter Cr. (3.8)	July 91	39	30	.76
Otter Cr. (6.8)	July 91	80	50	.63
Big Roche a Cri Cr. (1.6)	July 88	31	18	.58
Data from Forbes (1985):				
Galena R. (29.8)	July 81	185	103	0.56
Pats Cr. (1.6)	July 81	145	93	.64
Unpublished data from Mason, WDNR:				
Sinsinawa R. (14.4)	Aug. 88	62	32	0.52
Little Platte R. (19.1)	Sept. 88	364	192	.53
Data from Polomis (1988):				
Bear Cr., MN	Apr. 85	41	30	0.73
Bear Cr., MN	Sept. 85	21	11	.52
Bear Cr., MN	May 86	52	37	.71
Unpublished data from Merna, Michigan Department of Natural Resources:				
Huron R., MI (Station 1)	Oct. 86	47	33	0.70
Huron R., MI (Station 2)	Oct. 86	12	45	3.75
Huron R., MI (Station 5)	Oct. 86	41	15	.37
Huron R., MI (Station 6)	Oct. 86	34	24	.70
Huron R., MI (Station 7)	Oct. 86	75	66	.88
Huron R., MI (Station 1)	Oct. 87	45	14	.31
Huron R., MI (Station 2)	Oct. 87	30	27	.90
Huron R., MI (Station 4)	Oct. 87	56	48	.86
Huron R., MI (Station 5)	Oct. 87	49	23	.47
Huron R., MI (Station 6)	Oct. 87	61	53	.87
Huron R., MI (Station 7)	Oct. 87	84	50	.60

Discussion

Estimates from recapture sampling probably do not represent "typical" smallmouth bass population sizes for Wisconsin streams. Mark-recapture population estimates were made only at sites where CPUE sampling yielded moderate to high numbers of smallmouth bass for marking. At many other sites, catches during CPUE sampling were too small to justify recapture sampling. Presumably, these other sites had small populations. The mark-recapture population estimates in table 3 probably represent only the upper end of the range of population sizes existing in Wisconsin streams. Certainly, some Wisconsin smallmouth bass streams have fewer than 5.2 smallmouth bass per 100 m, our lowest mark-recapture population estimate.

The phenomenon of reduced smallmouth bass catches during the recapture run was not restricted to this study. We were able to obtain catch data from four other studies, one from Michigan (James Merna, Michigan Department of Natural Resources unpublished data), one from Minnesota (Polomis 1988), and two from Wisconsin (John Mason, WDNR unpublished data; Forbes 1985), in which biologists used a single stream shocker to estimate smallmouth bass population sizes by the same mark-recapture procedure. These four studies yielded a total of 18 population estimates. In 17 of these 18 estimates, the number of smallmouth bass $\geq$ age I caught during the recapture run was less than the number caught during the marking run (table 4). This number of occurrences was significantly more than expected by chance (sign test; $p < 0.0001$). A paired t-test of the catch in the marking run versus the recapture run indicated that catch in the recapture run was significantly lower ($t = 3.17$; $p = 0.0056$; catch data log transformed to approximate normality). For all 18 samples, the median value of the ratio of catch in the recapture run to catch in the marking run was 0.62; the range was 0.31 to 3.75.

Although the mark-recapture procedure is conceptually simple, it has several key requirements that must be met to produce a valid population estimate (after Ricker 1975):

1) Individual marked fish must not be any more or less likely to be captured during the recapture run than individual unmarked fish.
2) Increases in fish abundance within the study area between the marking and recapture runs (e.g., due to recruitment or immigration) must be negligible.
3) Any losses of fish from the study area between the marking and recapture runs (e.g., due to mortality or emigration) must affect marked and unmarked fish similarly.

The significant difference between the catches in the marking run and the recapture run, both in this study and in several others, suggest that one or more of these requirements may not have been met. If all the requirements had been satisfied, the number of smallmouth bass captured during the marking run would have been approximately equal to the number captured during the recapture run. Three processes would result in reduced catches during the recapture run: mortality, emigration, and reduced vulnerability to capture. If each of these processes affected both marked and unmarked smallmouth bass equally, then the difference in catch between the marking and recapture runs would have no influence on population estimates. However, if these processes affected marked smallmouth bass more than unmarked smallmouth bass, then resulting mark-recapture population estimates would be biased and inaccurate.

We are aware of only one published study that has examined the response of smallmouth bass to capture with an electroshocker. Green *et al.* (1987) found minimal mortality (< 1 percent) of smallmouth bass held in aerated live wells for 30 minutes to 1 week after capture by a DC boom shocker. Data from other species provide conflicting evidence as to whether mortality, emigration, or reduced vulnerability to capture are more likely to occur in marked fish than in unmarked fish. During a study of the response of cutthroat trout (*Oncorhynchus clarki*) to DC electroshocking, divers observed that trout that had been captured, marked, and released behaved very differently from trout that had not been captured (Mesa and Schreck 1989).

Physiological stress responses were also evident in the captured trout. Mesa and Schreck (1989) believed that these behavioral and physiological responses could lead to decreased vulnerability to recapture by marked fish. However, most of the responses to capture were gone within 24 hours, the minimum time between marking and recapture runs during our study. Similarly, several European fish species had reduced vulnerability to recapture for several hours after being captured with an electroshocker (Cross and Stott 1975), but this reduced vulnerability disappeared within 24 hours. Data on post-shocking mortality of fish other than smallmouth bass are equivocal; death rates of marked fish have ranged from negligible to substantial depending on the species, size of fish, type of electroshocker, and environmental conditions (summarized in Saul 1980, Barrett and Grossman 1988). We tried to minimize the stress experienced by captured smallmouth bass, and we never observed more than 5 percent short-term mortality (i.e., between initial capture and release) at a site. However, delayed mortality might have occurred.

Recommendations

Based on our own observations and on results from other studies, we cannot rule out the possibility that reduced catches during the recapture run occurred because marked smallmouth bass were less likely to be captured (due to mortality, emigration, reduced vulnerability, or some combination of factors) than those that were unmarked. As a result, we cannot be certain that our mark-recapture population estimates for smallmouth bass were accurate. Indeed, there is a strong possibility that at least some of these estimates were biased and inaccurate. If marked fish were less likely to be captured during the recapture run than unmarked fish, then population estimates would tend to be greater than the true population size, perhaps substantially so (Saul 1980). Until the exact cause of reduced catches during the recapture run is determined, it will be impossible to develop an effective procedure to quantify and correct for any possible biases in population estimates. Therefore, we do not recommend using mark-recapture procedures to study smallmouth bass populations in streams. Our analysis also calls into question the accuracy of previously published mark-recapture population estimates of smallmouth bass in streams.

MULTIPLE SHOCKER SAMPLING

Results

Ten multiple shocker samples were collected, seven with two shockers and three with three shockers (table 5). All but one of these samples came from relatively big streams (> 20 m wide); mean widths of sites ranged from 12.0 to 42.7 m. The pooled catch for smallmouth bass ≥ age I from the two or three shockers ranged from 0.5 to 17.7, with a median of 5.5. The catch of smallmouth bass > 203 mm TL ranged from 0.3 to 10.8, with a median of 1.9. The catch of smallmouth bass > 355 mm TL was extremely small, ranging from 0.0 to 0.1, with a median of 0.0. The highest values for all three age/size groups came from the Jump River in northwestern Wisconsin (Mile 6.9, June 1988, 3 shockers).

Catches of smallmouth bass were larger during multiple shocker sampling than during associated single-shocker CPUE sampling (table 5). At six of the seven sites where two stream shockers were used, the pooled catch in multiple shocker sampling averaged about twice the catch in CPUE sampling (≥ age I: unweighted mean of ratio = 2.6, range = 1.3 to 6.0; > 203 mm TL: mean = 2.3, range = 0.8 to 4.0; > 354 mm TL: insufficient captures for analysis). These six sites were wide enough (23.7 m to 42.7 m mean width) that two shockers together often could not simultaneously cover the entire width of the stream. At the seventh site, the West Fork of the Chippewa River (Mile 20.5, August 1989), no smallmouth bass were captured in CPUE sampling, but 34 were captured in multiple shocker sampling (11 > 203 mm TL; 0 > 354 mm TL). This site was the narrowest sampled with multiple shockers (12.0 m mean width), and two shockers together could easily cover the entire width of the stream. At the three sites where three stream shockers were used, the pooled catch in multiple shocker sampling was much more than three times the catch in CPUE sampling (≥ age I: unweighted mean of ratio = 7.4, range = 4.6 to 9.3; > 203 mm TL: mean = 11.9, range 7.2 to 15.0; > 354

Table 5.—*Comparison of smallmouth bass catches during CPUE sampling and multiple shocker sampling*

Stream (mile)	Time period	Mean width (m)	Smallmouth bass age/ size group	Catch per 100 m CPUE	Catch per 100 m Multiple	Ratio
			Two shockers used during multiple shocker sampling			
Milwaukee R. (64.4)	June 89	27.0	≥ Age I	4.1	9.2	2.2
			>203 mm TL	.6	1.5	2.5
			>354 mm TL	.0	.1	-[1]
Milwaukee R. (64.4)	June 90	26.7	≥ Age I	.4	.5	1.3
			>203 mm TL	.4	.3	.8
			>354 mm TL	.0	.0	-
Milwaukee R. (64.4)	June 91	23.7	≥ Age I	4.1	10.3	2.5
			>203 mm TL	2.3	4.0	1.7
			>354 mm TL	.1	.1	1.0
Embarrass (46.4)	Aug. 88	27.5	≥ Age I	.3	1.8	6.0
			>203 mm TL	.1	.4	4.0
			>354 mm TL	.0	.0	-
Oconto R.	Aug. 88	42.7	≥ Age I	.6	1.0	1.7
			>203 mm TL	.3	.6	2.0
			>354 mm TL	.0	.0	-
East Fork Chippewa R. (23.7)	Aug. 89	30.8	≥ Age I	.9	1.7	1.9
			>203 mm TL	.2	.5	2.5
			>354 mm TL	.0	.0	-
West Fork Chippewa R. (20.5)	Aug. 89	12.0	≥ Age I	.0	1.9	-
			>203 mm TL	.0	.9	-
			>354 mm TL	.0	.0	-
			Three shockers used during multiple shocker sampling			
West Fork Chippewa R. (14.5)	Aug. 89	27.6	≥ Age I	0.7	3.2	4.6
			>203 mm TL	.1	1.5	15.0
			>354 mm TL	.0	.0	-
Jump R. (3.3)	June 88	40.1	≥ Age I	.9	7.5	8.3
			>203 mm TL	.6	4.3	7.2
			>354 mm TL	.0	.1	-
Jump R. (6.9)	June 88	31.6	≥ Age I	1.9	17.7	9.3
			>203 mm TL	.8	10.8	13.5
			>354 mm TL	.0	.1	-

[1] *A "-" indicates that the ratio cannot be calculated.*

mm TL: insufficient captures for analysis). At these sites, which ranged from 27.6 to 40.1 m mean width, three shockers together could usually cover the entire width of the stream.

Because it involved two or three stream shockers as opposed to only one, multiple shocker sampling required two or three times the time and effort of CPUE sampling. At a site 1200 m long, a two-shocker sampling run typically required 18 to 36 person-hours of work, whereas a three-shocker run required 27 to 54 person-hours.

Discussion

The same sampling conditions and environmental factors that influenced catch during CPUE sampling likely also influenced catch during multiple shocker sampling. Consequently, all the issues and questions about the sampling efficiency and the accuracy and precision of CPUE sampling probably also apply to multiple shocker sampling.

The decline in availability of smallmouth bass for capture after CPUE sampling, as revealed by our analysis of recapture sampling results, probably caused reduced catches during subsequent multiple shocker sampling. Thus, the ratio of the catch in multiple shocker sampling versus the catch in CPUE sampling likely underestimated the true difference in sampling effectiveness between the two techniques. Nonetheless, this ratio still provided insight into the relationship between sampling effort and catch of smallmouth bass. At sites where multiple shockers could not cover the entire stream channel simultaneously, the use of two shockers resulted in a catch about twice that of a single shocker, suggesting a simple linear relation between the number of shockers and catch. However, when multiple shocker sampling could completely cover the channel, using two or three shockers together yielded far more than two or three times the catch of a single shocker, suggesting greatly increased sampling efficiency with multiple shockers.

Recommendations

Multiple shocker sampling and CPUE sampling are essentially identical in concept; and because of this, we believe that multiple shocker sampling, like CPUE sampling, can provide a reasonably accurate but not particularly precise index of smallmouth bass abundance. Thus, we recommend using multiple shocker sampling to track trends in abundance at a particular site or to compare abundances among sites with similar environmental characteristics. We have no data on the sampling error associated with multiple shocker sampling; and until such data are available, we recommend using the same rule of thumb as for CPUE sampling—a difference in catch rate between two multiple shocker samples should not be considered biologically meaningful unless it is more than 60 percent of the mean of the two samples or more than 0.6 smallmouth bass per 100 m, whichever is larger. We recommend against using multiple shocker results to compare smallmouth bass abundances among environmentally dissimilar sites. We also recommend against comparing data from samples involving different numbers of stream shockers. More data are needed on the relationships among catch, number of shockers, and stream width before such comparisons can be made without risk of serious error.

The question of whether to use CPUE sampling or multiple-shocker sampling in a study hinges on the tradeoff between the greater catches of smallmouth bass and the increased labor and equipment costs associated with multiple shocker sampling. The larger catches of multiple shocker sampling are always desireable, but use of a single shocker may be easier and more practical when labor or equipment are limited. If labor and equipment are not a limiting factor, we recommend using enough shockers to completely cover the width of the stream channel. For streams less than 16 m wide, this may be only one shocker; although at relatively deep and structurally complex sites, such as the West Fork Chippewa River site

(Mile 20.5), two shockers are often much more effective than one. At sites from 16 to 24 m wide, two shockers are usually sufficient, and at sites wider than 24 m, three shockers will produce the best results. At relatively deep sites, it may be worthwhile to substitute a mini-boom shocker for one of the stream shockers to more effectively sample the thalweg.

REMOVAL SAMPLING

Results

We conducted removal sampling at six sites on three relatively wide rivers in northern Wisconsin (NLF ecoregion). Estimated population sizes ranged from 0.6 to 7.9 per 100 m for smallmouth bass ≥ age I (table 6), with a median value of 2.0. The maximum value occurred in the Yellow River (Mile 59.7, August 1989).

The accuracy of our relatively small population estimates was supported by other data and observations. At all six sites, CPUE catches were also relatively low, and removal population estimates and CPUE catches were positively correlated (Spearman Rank Correlation = 0.64, $p = 0.174$; fig. 4). We tried angling at four of the sites (Yellow and South Fork Flambeau Rivers) and caught few smallmouth bass, most of which had been previously captured and marked during CPUE or removal sampling. We had our best fishing by far at the Yellow River site, which also had the highest population estimate, with an angling catch of 0.9 smallmouth bass ≥ age I per 100 m in 27 angler-hours. The few other anglers that we met during our sampling of the six sites had also had poor fishing for smallmouth bass. We snorkeled through part of one site (South Fork Flambeau River, Mile 62.5) and observed no smallmouth bass.

Table 6.—*Population estimates from removal sampling*

Stream (mile)	Time period	Mean width m	Distance sampled and site length m	Population estimate and 95% confidence interval number per 100 m
Yellow R. (59.7)	Aug. 89	18.1	590 1250	7.9 3.0 - 14.7
South Fork Flambeau R. (58.9)	July 89	23.3	530 1200	1.9 1.1 - 2.6
South Fork Flambeau R. (62.5)	July 89	27.3	480 800	1.7 1.7 - 2.9
South Fork Flambeau R. (66.6)	July 89	18.0	350 1200	2.3 0.6 - 3.1
Manitowish R. (11.1)	Aug. 90	25.3	330 850	0.6 0.6 - 1.2
Manitowish R. (31.1)	Aug. 89	18.7	240 1250	2.1 2.1 - 2.9

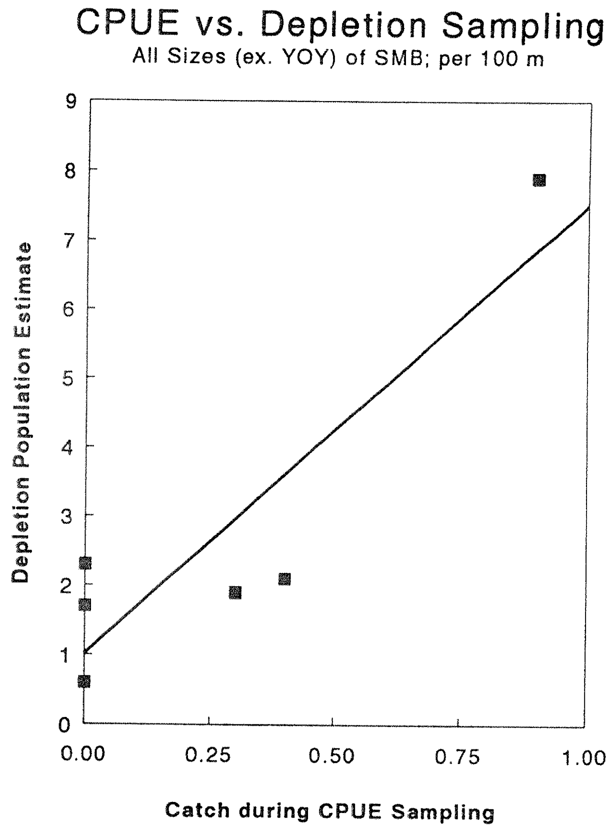

Figure 4.—*Plot of catch per 100 m during CPUE sampling versus estimated population size per 100 m based on removal sampling for six sampling events.*

Removal sampling was by far the most time consuming and labor intensive approach that we used to estimate smallmouth bass abundance. The amount of sampling effort expended for removal sampling depended largely on the width of the stream, with wider streams needing more stream shockers and personnel, and on the rate at which smallmouth bass numbers could be reduced during sampling, with slower rates dictating more passes. The six sites that we sampled all required three stream shockers or two stream shockers plus a mini-boom shocker and three to five passes per segment within each site.

The amount of effort involved in our removal sampling can be broken down as follows. Removal sampling was conducted in three to seven 50- to 200-m-long segments within each site, and these segments in total encompassed from 20 to 60 percent of site length (table 6). For each segment, it took three people about 1 hour to set up and then later pull out the two block nets that bounded the segment, for a total of 3 person-hours. On a narrower stream, the amount of time required to set and pull the block nets would be reduced, but would never be less than 20 minutes. Each pass through the segment, including returning to the beginning of the segment to start the next pass, took the nine people involved from 20 minutes to 1 hour, depending on the length of the segment and the number of smallmouth bass captured, for a total of 3 to 9 person-hours. Processing the sample of smallmouth bass and checking and clearing debris from the block nets in preparation for the next pass took the nine people from 10 to 30 minutes for a total of 1.5 to 4.5 person-hours. In total, a three-pass removal of a typical segment took from 22.5 to 49.5 person-hours, whereas a five-pass segment could take up to 82.5 person-hours. Summing the effort for all segments gave a total removal sampling effort for a site of 100 to 180 person-hours, roughly four times the effort for multiple shocker sampling and more than 10 times the effort for CPUE sampling. If we had conducted removal sampling over the entire length of each site, sampling effort would have been about 200 to 350 person-hours. Clearly, removal sampling effort would have been less for narrower streams where fewer stream shockers were required, but still would have been substantially more than for multiple shocker or CPUE sampling.

Discussion

Removal sampling took place only on three relatively large and unproductive streams in northern Wisconsin, and the resulting population estimates were not representative of the entire range of smallmouth bass populations occurring in Wisconsin streams. Many other sites certainly had abundances greater than 7.9 smallmouth bass per 100 m, the maximum estimated value during removal sampling. Indeed, during 15 sampling events, all on southern Wisconsin streams, the catch of smallmouth bass during CPUE sampling was larger than 7.9 per 100 m. The results of removal sampling were consistent with CPUE sampling and angling results, and support the idea that northern Wisconsin streams typically support relatively low densities of smallmouth bass.

The "catchability" of fish—the probability that a fish will be captured during a particular sampling pass—has a major influence on the accuracy of population estimates derived from removal sampling (Otis *et al.* 1978, White *et al.* 1982, Schnute 1983, Bayley 1985). Most removal population estimation techniques assume that catchability is constant among fish and among sampling passes. If catchability varies substantially among fish or passes, then population sizes estimated by these techniques will be inaccurate. We attempted to minimize variation in catchability among passes by using identical procedures during each pass. However, in some instances, the act of making a shocking pass affected the habitat within the segment, through disruption of macrophyte beds or movement of large woody debris to permit easier passage of the shockers, leading to more favorable shocking conditions and perhaps increased catchability during subsequent passes. Such an increase in catchability could cause an overestimate of population size. However, significant overestimates were not a problem at most of our sites because the estimated population sizes were usually equal to or only slightly larger than the total number of smallmouth bass that we actually caught during the removal sampling.

It is extremely unlikely that all the smallmouth bass within our sites had equal catchabilities. Although no one has studied individual variability in stream shocker catchability for smallmouth bass, every species that has been studied has shown substantial individual variability (Mahon 1980, Saul 1980, Peterson and Cederholm 1984, Gatz and Loar 1988, Bohlin and Cowx 1990). When there is significant variability in catchability among individual fish, termed "heterogeneity," the fish with higher catchabilities are captured and removed in disproportionally greater numbers during the early sampling passes, and the overall average catchability of the remaining (*i.e.*, not yet removed) fish declines with each succeeding pass. Such a pattern of decline in catchabilities among passes will lead to an underestimate, possibly severe, of population size (Otis *et al.* 1978, White *et al.* 1982). Otis *et al.* (1978) developed a "generalized removal" population estimation model that allows for heterogeneity in catchability. White *et al.* (1982) tested this generalized model with published data on removal sampling of fish and found that it gave much less biased results than estimation techniques that assumed equal catchabilities among fish. We used the generalized model for our removal population estimates, and we believe that our results are reasonably accurate.

Recommendations

Of the two techniques for estimating smallmouth bass population size that we examined, mark-recapture and removal, we recommend using the removal technique. Although we gave it only a limited trial, removal sampling appeared to yield relatively accurate and precise population estimates. Conversely, recapture sampling may have resulted in highly biased estimates. Moreover, removal sampling should yield an accurate population estimate at essentially any density of smallmouth bass, whereas mark-recapture sampling is usually justified only at sites with densities of smallmouth bass high enough so that at least a few smallmouth bass are likely to be marked and recaptured.

We recommend using the generalized removal model of Otis *et al.* (1978), which does not assume equal catchability among all passes, to make removal population estimates of smallmouth bass in streams. We are certain that smallmouth bass, like all other species examined thus far, exhibit substantial individual variation in vulnerability to capture, and thus a model that assumes constant catchability may yield a biased estimate. The generalized removal model requires at least four passes to take advantage of its variable catchability feature because the number of catchability estimates that the model can generate is equal to the number of passes minus two.

The major problem with removal sampling is the large amount of effort required. In many instances, particularly on larger streams where multiple shockers are needed, the amount of time and labor necessary to generate a valid removal population estimate will be prohibitive. We recommend carefully considering whether or not a population estimate is really needed before undertaking removal sampling. Often, it will not be cost-effective to try and obtain a population estimate by the removal method. We believe that in most routine monitoring and assessment projects, CPUE or multiple shocker sampling, which requires far less effort than removal sampling, will provide results that are sufficiently accurate and detailed for management purposes. We recommend that removal sampling be reserved for studies where accurate and precise population estimates are essential.

For removal sampling, we recommend conducting sampling during mid-July to mid-September, and avoiding removal sampling soon after floods. We recommend following the multiple shocker sampling guidelines for determining the number of shockers to use at a site during removal sampling.

SUMMARY AND OVERALL RECOMMENDATIONS

We examined and compared the usefulness of four common electroshocking procedures, all involving standard WDNR stream shockers, in estimating the abundance of smallmouth bass in Wisconsin streams. Our goal was to identify cost-effective, standardized procedures that could be used to assess the abundance of smallmouth bass in streams of Wisconsin and surrounding areas. We collected data during 189 discrete sampling events at a total of 90 sites on 60 streams located throughout Wisconsin. These streams were representative of a wide range of smallmouth bass stream habitats, and included several that were reported to have excellent smallmouth bass angling.

Catch-per-unit-effort (CPUE) sampling was conducted during all 189 sampling events. The other three procedures were done only during small subsets of the events, and followed CPUE sampling. Catch-per-unit-effort sampling consisted of a single pass upstream through a site with a single stream shocker, during which an attempt was made to capture all smallmouth bass observed. The catch of smallmouth bass per 100 m of stream length sampled was used as an index of abundance. Recapture sampling consisted of an upstream pass with a single shocker to mark all smallmouth bass that could be captured (CPUE sample), and a second upstream (recapture) pass with one, two, or three shockers to attempt to capture all marked and unmarked smallmouth bass observed. Results were used to calculate a Petersen mark-recapture population estimate (Ricker 1975). Multiple shocker sampling was conducted in the same manner as CPUE sampling except that two or three stream shockers were used together instead of one, and the combined catch per 100 m was used as the index of abundance. In removal (depletion) sampling, segments of sites were isolated by block nets and repeatedly shocked with multiple shockers. Smallmouth bass were removed from the segment as they were captured until sufficient data were collected to make a removal population estimate using the generalized removal model of Otis *et al.* (1978).

Based on our results, we believe that CPUE sampling that is conducted in a consistent and standardized manner can provide a reasonably accurate, although fairly imprecise, index of the relative abundance of smallmouth bass at a single site over time or among sites with similar environmental characteristics. However, CPUE sampling is not a good method for comparing smallmouth bass abundances between sites that differ substantially in environmental characteristics (*e.g.*, conductivity, water velocity, width, depth, water clarity, or other physical/chemical conditions) because differences in catch may reflect differences in stream-shocker capture efficiency rather than true differences in population size. We recommend using CPUE sampling to develop time series of smallmouth bass abundance at specific sites to determine abundance trends. We also recommend using CPUE sampling for the initial reconnaissance of potential study sites because it requires the least time, personnel, and equipment of the four that we examined. Because of the imprecision inherent in CPUE sampling, we suggest that little significance be given to differences in catch between samples unless they exceed 60 percent of the mean of the samples or 0.6 smallmouth bass per 100 m, whichever is larger. We recommend that studies be undertaken to quantify sources of variation in capture efficiency during CPUE sampling, so that correction factors can be developed to permit comparison of CPUE samples from environmentally different sites, and ultimately to allow conversion of smallmouth bass catches into population estimates.

We recommend multiple shocker sampling as an alternative to CPUE sampling at sites with mean widths greater than 16 m and at narrower sites that are relatively deep or structurally complex. The use of extra stream shockers obviously requires more equipment and personnel, but almost invariably results in a much larger catch of smallmouth bass. As with CPUE sampling, multiple shocker sampling is best used to estimate abundance trends over time at a single site or to compare relative abundances among several sites with similar environmental characteristics. We recommend against comparing catches from multiple shocker samples taken from sites that differ substantially in environmental characteristics because capture efficiency will probably differ among sites. We also recommend against comparing samples collected with different numbers of shockers because the relationship between the number of shockers used and catch is not straightforward. A study to help better understand this relationship would be useful.

We advise against conducting recapture sampling. There is a strong possibility that some of the key assumptions that underlie mark-recapture population estimation models are violated during recapture sampling of smallmouth bass in streams, and it is likely that many population estimates that result from recapture sampling will be unacceptably biased.

We recommend removal sampling when an estimate of the actual population size of smallmouth bass at a site is required. Removal sampling appears to yield reasonably accurate and precise population estimates of smallmouth bass if at least four passes are made and the generalized removal population estimation model of Otis *et al.* (1978) is used. However, removal sampling is labor intensive and may be impractical in many situations. We recommend undertaking removal sampling only during intensive studies where an actual population estimate is essential. Additional studies comparing removal sampling population estimates with CPUE and multiple shocker sampling catches would be valuable in quantifying relationships between actual population sizes and indices of abundance.

We recommend that smallmouth bass sampling in the streams of Wisconsin and surrounding areas be conducted during the summer, preferably between mid-July and mid-September. During other times of the year, smallmouth bass seasonal movements may cause inaccurate estimates of the number of smallmouth bass available to anglers during the summer. Sampling immediately after a summer flood may also result in a biased estimate of normal summer smallmouth bass abundance; we recommend at least a 1-week interval between the end of a flood and the initiation of sampling.

ACKNOWLEDGMENTS

We thank the many biologists, technicians, and field assistants from the Wisconsin Department of Natural Resources, the Nicolet and Chequamegon National Forests, and the North Central Forest Experiment Station, USDA Forest Service, who helped us collect these data. Paul Rasmussen provided helpful advice on statistics and computer programming. We are grateful to Clay Edwards, Randy Sauer, Paul Seelbach, and Mike Staggs for reviews that helped improve this manuscript. This research was funded by the WDNR, Bureau of Research; Sport Fish Restoration Program, Project F-83-R, Studies 043 and 046; and the U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, Wildlife and Fish Habitat Research Unit NC-4202.

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APPENDIX

Catch per 100 m of smallmouth bass for the 189 CPUE sampling events. Code refers to the location of each stream on figure 1. Mile is the distance (via the channel) from the downstream edge of the station to the mouth of the stream and is used to indicate station location. A "-" indicates no data.

Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
				DRIFTLESS AREA ECOREGION				
Bad Axe River System								
1	North Fork Bad Axe R. (4.3)	880723	1200	7.9	-	0.6	0.3	0.0
1	North Fork Bad Axe R. (4.3)	910724	1200	7.4	-	.5	.4	.1
1	North Fork Bad Axe R. (8.1)	880721	1200	8.3	-	2.5	.9	.2
1	North Fork Bad Axe R. (8.1)	910723	1200	7.9	-	2.3	1.5	.2
1	North Fork Bad Axe R. (12.7)	910731	1000	14.2	-	6.8	6.0	.2
1	North Fork Bad Axe R. (16.7)	880727	1200	7.4	-	.8	.2	.1
Grant, Platte, and Galena River Systems								
2	Pigeon Cr. (1.6)	910716	200	6.4	-	12.0	9.5	1.0
2	Pigeon Cr. (1.6)	910828	200	-	25.5	13.0	8.0	.0
2	Pigeon Cr. (1.6)	920710	220	6.7	-	15.5	5.9	.5
2	Pigeon Cr. (1.6)	920824	220	-	16.4	11.4	4.1	.0
2	Pigeon Cr. (6.7)	910717	250	6.0	-	2.8	2.0	.0
2	Pigeon Cr. (6.7)	910828	250	-	.0	3.2	2.4	.0
2	Pigeon Cr. (6.7)	920706	250	6.0	-	4.8	.0	.0
2	Pigeon Cr. (6.7)	920824	480	-	1.0	2.7	.6	.0
3	Rattlesnake Cr. (4.4)	870609	1300	9.1	-	4.2	4.0	.2
3	Rattlesnake Cr. (4.4)	890906	1300	-	9.5	3.7	.6	.0

(Appendix continued on next page)

Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
3	Rattlesnake Cr. (4.4)	900917	1300	10.1	0.5	13.6	4.2	0.0
3	Rattlesnake Cr. (4.4)	910905	1300	-	13.8	5.6	5.3	.2
3	Rattlesnake Cr. (4.4)	920825	1300	-	6.9	9.9	5.3	.8
3	Rattlesnake Cr. (7.3)	900917	800	-	.0	.0	.0	.0
3	Rattlesnake Cr. (7.3)	910717	450	10.1	-	.5	.5	.0
3	Rattlesnake Cr. (7.3)	910906	800	-	3.4	.0	.0	.0
3	Rattlesnake Cr. (7.3)	920715	450	9.9	-	2.7	.4	.0
3	Rattlesnake Cr. (7.3)	920826	800	-	.9	1.9	.5	.0
3	Rattlesnake Cr. (9.5)	900918	800	7.6	.0	.0	.0	.0
3	Rattlesnake Cr. (9.5)	910905	800	-	.3	.0	.0	.0
3	Rattlesnake Cr. (9.5)	920826	800	-	1.6	.0	.0	.0
3	Rattlesnake Cr. (10.1)	900918	800	-	.0	1.1	.7	.0
3	Rattlesnake Cr. (10.1)	910709	275	5.8	-	2.0	2.0	.0
3	Rattlesnake Cr. (10.1)	910904	800	-	.3	.4	.4	.0
3	Rattlesnake Cr. (10.1)	920708	275	-	-	1.8	2.0	.0
3	Rattlesnake Cr. (10.1)	920826	800	-	.6	.8	.0	.0
4	Boice Cr. (6.9)	900913	300	6.8	3.7	2.0	.0	.0

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Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
5	Menominee Cr. (7.5)	870716	1450	7.1	-	0.0	0.0	0.0
6	Sinsinawa R. (12.8)	870706	1800	11.2	-	.2	.2	.1
6	Sinsinawa R. (12.8)	900913	1800	-	.0	.0	.0	.0
6	Sinsinawa R. (12.8)	910828	1800	-	.0	.0	.0	.0
6	Sinsinawa R. (12.8)	920827	1800	-	2.7	.4	.1	.0
7	Little Platte R. (19.1)	870625	1200	16.5	-	2.0	1.8	.2
7	Little Platte R. (19.1)	890707	1200	-	-	10.0	4.8	.5
7	Little Platte R. (19.1)	890907	1200	-	28.4	9.8	4.1	.2
7	Little Platte R. (19.1)	900628	1200	15.5	-	8.6	3.2	.3
7	Little Platte R. (19.1)	900709	1200	-	-	4.9	2.8	.1
7	Little Platte R. (19.1)	900912	1200	15.5	1.2	13.9	6.0	.2
7	Little Platte R. (19.1)	901113	1200	-	.2	1.2	.6	.0
7	Little Platte R. (19.1)	910319	1200	-	-	.2	.0	.0
7	Little Platte R. (19.1)	910529	1200	-	-	7.3	3.8	.3
7	Little Platte R. (19.1)	910701	1200	-	-	6.6	3.3	.1
7	Little Platte R. (19.1)	910827	1200	-	.8	13.3	8.1	.3
7	Little Platte R. (19.1)	911113	1200	-	.0	.8	.8	.0

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Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
7	Little Platte R. (19.1)	920701	960	15.1	-	10.8	6.0	0.5
7	Little Platte R. (19.1)	920818	1200	-	9.8	9.8	7.3	1.1
8	Galena R. (29.8)	870701	1900	14.0	-	6.4	3.2	.2
8	Galena R. (29.8)	900907	1900	18.6	.3	8.6	7.5	1.4
8	Galena R. (29.8)	910702	1900	17.9	-	3.9	3.8	1.0
8	Galena R. (29.8)	910826	1900	-	6.4	6.2	5.8	1.1
8	Galena R. (29.8)	920901	1900	-	1.9	18.3	4.8	2.3
9	Pats Cr. (1.6)	870707	1200	4.4	-	1.7	1.5	.0
9	Pats Cr. (1.6)	910906	800	-	5.6	.0	.0	.0
Pecatonica River System								
10	Livingston Br. (1.9)	870623	1250	5.5	-	0.0	0.0	0.0
10	Livingston Br. (0.3)	890830	1500	-	5.6	1.0	.6	.0
10	Livingston Br. (0.3)	900911	1500	6.1	.4	7.1	4.8	.0
10	Livingston Br. (0.3)	910830	1500	-	1.5	6.1	3.7	.1
10	Livingston Br. (0.3)	920831	1500	-	.6	4.4	1.7	.4
11	Mineral Point Br. (12.3)	870714	1200	7.0	-	3.7	1.0	.0
11	Mineral Point Br. (12.3)	890830	1200	5.8	33.4	18.0	5.8	.1
11	Mineral Point Br. (12.3)	900417	1200	-	-	6.4	2.3	.2
11	Mineral Point Br. (12.3)	900522	1200	-	-	6.9	3.1	.1
11	Mineral Point Br. (12.3)	900705	1200	6.8	-	3.1	.9	.1

(Appendix continued on next page)

Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
11	Mineral Point Br. (12.3)	900905	1200	-	4.3	6.3	3.3	0.2
11	Mineral Point Br. (12.3)	901113	1200	-	2.4	14.4	6.6	.1
11	Mineral Point Br. (12.3)	910319	1200	-	-	5.1	2.6	.2
11	Mineral Point Br. (12.3)	910529	1200	-	-	5.8	2.9	.0
11	Mineral Point Br. (12.3)	910701	1200	-	-	7.7	2.5	.2
11	Mineral Point Br. (12.3)	910829	1200	-	39.2	6.9	3.3	.1
11	Mineral Point Br. (12.3)	911113	1200	-	5.1	4.8	3.9	.1
11	Mineral Point Br. (12.3)	920703	1200	7.3	-	13.4	3.4	.1
11	Mineral Point Br. (12.3)	920903	1200	-	16.1	13.9	3.7	.2
12	Ames Br. (4.1)	910716	1200	7.3	-	4.1	4.1	.2
12	Ames Br. (4.1)	910830	1430	-	7.3	4.8	4.5	.2
12	Ames Br. (4.1)	920826	1430	-	.1	11.9	3.1	.1
13	Otter Cr. (0.4)	910715	1200	9.0	-	2.4	2.2	.0
13	Otter Cr. (0.4)	920824	1200	-	.3	3.9	2.3	.0
13	Otter Cr. (3.8)	900706	1200	8.8	-	1.0	.4	.0
13	Otter Cr. (3.8)	900907	1200	-	.1	1.6	.0	.0
13	Otter Cr. (3.8)	910709	1200	8.9	-	3.0	3.0	.2
13	Otter Cr. (3.8)	910829	1200	-	.0	3.2	2.6	.0
13	Otter Cr. (3.8)	920824	740	-	1.8	2.8	2.8	.3
13	Otter Cr. (6.8)	900706	1300	8.2	-	1.2	1.0	.1
13	Otter Cr. (6.8)	900905	1300	-	.0	1.5	.7	.0

(Appendix continued on next page)

Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
13	Otter Cr. (6.8)	910710	1300	8.6	-	5.7	5.5	0.0
13	Otter Cr. (6.8)	910829	1300	-	0.0	5.3	5.2	.0
13	Otter Cr. (6.8)	920825	1160	-	.1	.8	.6	.0
14	Richland Cr. (23.7)	890906	1000	8.1	6.5	.1	.0	.0
Wisconsin River System								
15	Honey Cr. (5.2)	920727	290	10.9	-	0.7	0.0	0.0
16	Baraboo R. (3.2)	920727	700	28.0	-	6.1	1.9	.0
17	Seeley Cr. (3.4)	920727	140	8.5	-	2.9	.0	.0
18	Narrows Cr. (3.2)	890831	400	10.6	1.3	4.1	.8	.0
	SOUTHEASTERN WISCONSIN TILL PLAINS ECOREGION							
Rock River System								
19	Crawfish R. (37.6)	880531	1400	24.0	-	0.2	0.0	0.0
19	Crawfish R. (38.4)	880525	1400	33.0	-	1.3	.3	.0
19	Crawfish R. (39.3)	880527	1600	31.6	-	3.2	.2	.0
19	Crawfish R. (39.3)	910604	1600	32.8	-	1.7	.7	.0
Fox River (South) System								
20	Fox R. (132.9)	910923	1600	42.5	4.9	3.4	3.0	0.3
21	White R. (4.5)	910923	500	11.5	2.4	1.0	.8	.0
Pike River System								
22	Pike R. (8.1)	900608	1020	11.1	-	0.2	0.2	0.0
23	South Branch Pike R. (0.2)	900606	840	6.8	-	.2	.0	.0
Milwaukee River System								
24	Milwaukee R. (53.1)	870827	1700	41.3	2.7	5.0	3.4	0.4

(Appendix continued on next page)

Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
24	Milwaukee R. (53.1)	910826	1700	-	6.4	12.5	7.4	0.9
24	Milwaukee R. (64.4)	880608	1200	22.2	-	4.4	1.5	.1
24	Milwaukee R. (64.4)	890614	1200	27.0	-	4.1	.6	.0
24	Milwaukee R. (64.4)	900620	1200	26.7	-	.4	.4	.0
24	Milwaukee R. (64.4)	910615	1200	23.7	-	4.1	2.3	.1
24	Milwaukee R. (64.4)	920601	1200	-	-	4.3	1.5	.0
24	Milwaukee R. (65.2)	880608	1200	11.9	-	.9	.1	.0
24	Milwaukee R. (65.2)	890613	1200	14.5	-	1.4	.0	.0
24	Milwaukee R. (65.2)	900622	1200	15.4	-	.4	.3	.0
24	Milwaukee R. (65.2)	910612	1200	16.4	-	12.2	4.0	.0
24	Milwaukee R. (65.2)	920602	1200	-	-	18.2	1.8	.0
24	Milwaukee R. (65.8)	880610	1300	18.8	-	.1	.0	.0
24	Milwaukee R. (65.8)	910611	1300	17.4	-	7.9	2.4	.0
24	Milwaukee R. (65.8)	920602	1300	-	-	3.3	.5	.0
24	Milwaukee R. (66.6)	880613	1000	16.9	-	.3	.2	.0
24	Milwaukee R. (66.6)	890614	1000	20.5	-	5.2	.4	.0
24	Milwaukee R. (66.6)	900620	1000	20.4	-	0.5	0.4	.0

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(Appendix cont.)

Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
24	Milwaukee R. (66.6)	910612	1000	20.4	-	47.8	5.4	0.0
24	Milwaukee R. (66.6)	920605	1000	20.4	-	21.9	4.6	.3
24	Milwaukee R. (69.2)	920611	1000	25.9	-	.0	.0	.0
25	N. Br. Milwaukee R. (4.3)	870824	1200	17.3	0.0	.8	.5	.3
25	N. Br. Milwaukee R. (4.3)	890609	1200	21.6	-	.2	.2	.0
25	N. Br. Milwaukee R. (4.3)	900620	1200	18.3	-	.2	.0	.0
25	N. Br. Milwaukee R. (4.3)	910628	1200	18.1	-	.6	.5	.1
25	N. Br. Milwaukee R. (4.3)	920610	1200	-	-	.2	.2	.0
Sheboygan River System								
26	Sheboygan R. (7.6)	910924	450	20.0	110.2	60.8	24.4	2.6
Twin River System								
27	West Twin R. (16.8)	890606	1050	22.4	-	0.3	0.3	0.0
	NORTH CENTRAL HARDWOODS FOREST ECOREGION							
Fox River (North) System								
28	Mecan R. (9.1)	880830	1200	12.0	1.3	0.4	0.2	0.0
29	White R. (14.6)	880829	1200	14.3	.4	.3	.0	.0
Wolf River System								
30	Little Wolf R. (9.7)	880806	1400	33.0	19.4	1.3	0.1	0.0
30	Little Wolf R. (9.7)	910805	1400	-	6.1	3.5	.5	.0
31	Embarrass R. (46.4)	880803	1300	27.5	7.7	.3	.1	.0
32	South Branch Embarrass R. (5.2)	920805	500	25.0	.0	1.0	.0	.0

(Appendix continued on next page)

Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
33	Middle Branch Embarrass R. (20.8)	920805	650	16.0	0.0	0.0	0.0	0.0
Pensaukee River System								
34	Pensaukee R.	920819	900	16.0	9.9	0.0	0.0	0.0
Oconto River System								
35	Oconto R. (28.4)	880810	1400	42.7	8.9	0.6	0.3	0.0
36	Little R. (8.4)	920818	400	26.0	6.5	4.0	2.0	.3
Wisconsin River System								
37	Big Roche a Cri Cr. (1.6)	880706	1200	12.9	-	2.3	0.5	0.2
37	Big Roche a Cri Cr. (6.4)	880709	1200	13.3	-	.4	.1	.0
38	Big Plover R. (7.1)	880714	1200	18.3	-	.6	.0	.0
38	Big Plover R. (8.5)	880713	1200	16.1	-	1.1	.3	.0
39	Big Eau Pleine R. (21.3)	920803	400	20.0	.8	2.0	1.8	.0
40	Eau Claire R. (3.7)	920804	600	32.0	2.3	2.7	.2	.0
40	Eau Claire R. (6.5)	920804	500	30.0	5.8	3.0	1.4	.2
41	Big Rib R. (12.8)	870727	1200	22.3	4.3	.4	.1	.0
41	Big Rib R. (14.4)	870806	1250	31.0	5.5	2.1	.5	.0
41	Big Rib R. (16.3)	870808	1200	29.2	13.1	.3	.0	.0
41	Big Rib R. (17.7)	870805	1200	32.1	5.5	.5	.0	.0
41	Big Rib R. (18.7)	870805	1200	26.2	4.2	.4	.1	.0
41	Big Rib R. (18.7)	920803	1200	25.0	1.1	.6	.5	.0

(Appendix continued on next page)

(Appendix cont.)

Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
Black River System								
42	Popple R. (0.6)	920622	520	22.7	-	1.5	0.4	0.0
Chippewa River System								
43	S. Fork Eau Claire R. (24.2)	900719	1100	19.1	-	0.5	0.2	0.0
44	N. Fork Eau Claire R. (11.2)	900720	1100	13.9	-	.1	.0	.0
St. Croix River System								
45	Willow R. (12.9)	890621	1200	17.0	-	1.6	1.1	0.1
NORTHERN LAKES AND FORESTS ECOREGION								
St. Croix River System								
46	Namekagon R. (30.6)	920625	650	27.0	-	1.2	0.2	0.0
46	Namekagon R. (51.4)	920625	600	27.0	-	.3	.0	.0
47	St. Croix R. (147.8)	920624	650	37.0	-	.0	.1	.0
48	Moose R. (0.8)	890623	900	13.9	-	.1	.1	.0
Chippewa River System								
49	Yellow R. (59.7)	890714	1250	18.1	-	0.9	0.3	0.0
49	Yellow R. (59.7)	920706	1250	18.8	-	.3	.2	.0
50	Jump R. (3.3)	880623	1700	40.1	-	.9	.6	.0
50	Jump R. (6.9)	880627	1200	31.6	-	1.9	.8	.0
51	Thornapple R. (8.4)	920624	410	18.8	-	1.7	1.5	.2
52	Moose R. (2.5)	890816	1100	9.4	.0	.0	.0	.0
53	W. Fork Chippewa R. (14.5)	890816	1200	27.6	.8	.7	.1	.0
53	W. Fork Chippewa R. (20.5)	890819	1200	12.0	.0	.0	.0	.0
54	E. Fork Chippewa R. (23.7)	890819	1200	30.8	.1	.9	.2	.0

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Code	Stream (Mile)	Date (YYMMDD)	Site length (m)	Mean width (m)	Catch per size/age group (Number per 100 m) YOY	≥Age I	>203	>354
55	S. Fork Flambeau R. (58.9)	880817	1200	22.8	6.9	0.9	0.3	0.0
55	S. Fork Flambeau R. (58.9)	890714	1200	23.3	-	.3	.0	.0
55	S. Fork Flambeau R. (58.9)	920817	1200	-	.4	.5	.5	.0
55	S. Fork Flambeau R. (62.5)	890707	800	27.3	-	.0	.0	.0
55	S. Fork Flambeau R. (66.6)	880816	1200	16.9	.5	.1	.0	.0
55	S. Fork Flambeau R. (66.6)	890707	1200	18.0	-	.0	.0	.0
56	Manitowish R. (11.1)	900731	850	25.3	1.2	.0	.0	.0
56	Manitowish R. (31.1)	890802	1250	18.7	.6	.4	.4	.0
Wolf River System								
57	Wolf R. (154.5)	920804	800	34.0	0.8	0.9	0.8	0.0
Peshtigo River System								
58	Peshtigo R. (46.7)	920818	900	33.0	6.6	0.1	0.1	0.0
59	Rat R. (12.5)	890806	800	28.5	.3	.0	.0	.0
Menominee River System								
60	Pine R. (10.3)	920817	700	35.0	2.7	0.4	0.1	0.0

☆U.S. GOVERNMENT PRINTING OFFICE: 1993 - 758-535/80044

Lyons, John; Kanehl, Paul.
1993. **A comparison of four electroshocking procedures for assessing the abundance of smallmouth bass in Wisconsin streams.** Gen. Tech. Rep. NC-159. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 35 p.

Critically examines four electrofishing methods commonly used to estimate the abundance of smallmouth bass in wadeable streams, and provides guidelines for sampling smallmouth bass in streams of Wisconsin and nearby areas.

KEY WORDS: Electrofishing, smallmouth bass, *Micropterus dolomieu*, fisheries management

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION