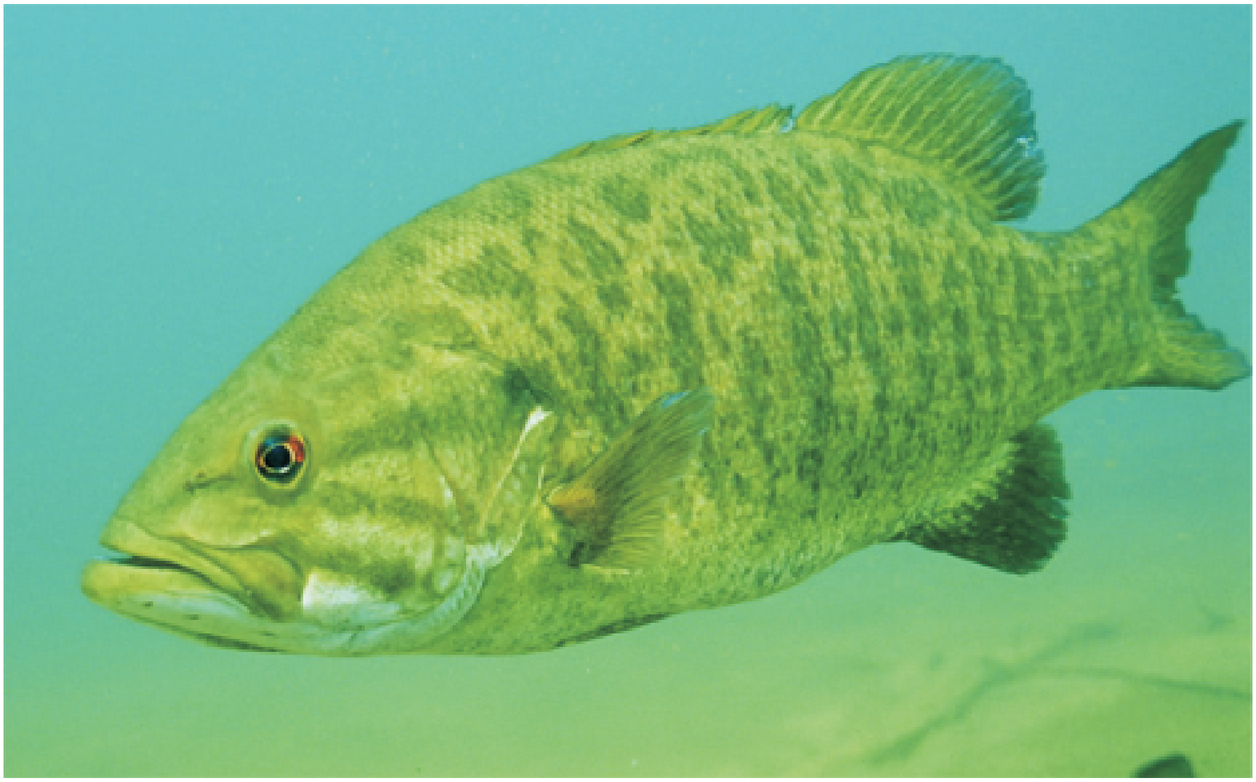

A sampling framework for smallmouth bass in Wisconsin's streams and rivers

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December 2006

INTRODUCTION

In summer 2006, an ad hoc committee of WDNR biologists was convened to develop field sampling and data interpretation guidelines for smallmouth bass fishery management in Wisconsin's stream and rivers. The committee was given three specific tasks:

1) Develop a simple yet accurate stream and river classification based on smallmouth bass population potential for determining the distribution of sampling effort and for the interpretation of sampling results;

2) Recommend appropriate sampling techniques and effort and an associated sampling design for each stream/river class and provide estimates of sampling accuracy and precision; and

3) Propose quantitative criteria based on the sampling techniques for each class to determine if fisheries management objectives were being met.

The committee exchanged information electronically and met face-to-face on two separate occasions. Team members worked effectively together and should be commended for their professionalism and dedication to the task. The fruits of their labor are presented here as *A sampling framework for smallmouth bass in Wisconsin's streams and rivers*.

METHODS

Recommendations were generated from review and interpretation of over 20 years of published research on the distribution, habitat, life history, and fishery management of smallmouth bass in Wisconsin's streams and rivers, coupled with new analyses of four existing smallmouth bass datasets managed by WDNR Fish Research. Two of the datasets covered wadable streams and rivers and two covered non-wadable rivers, and all four contained smallmouth bass catch and size data collected by daytime electrofishing during the summer months. The first, termed the "wadable spatial variation" (WSV) dataset, was from stream shocker surveys of 48 different wadable 0.3-1.2-mile long sites on 40 smallmouth bass streams located throughout the state, each sampled once between 1987 and 1992 (Lyons and Kanehl 1993). The second, termed the "wadable temporal variation" (WTV) dataset, had stream shocker surveys from single wadable 0.75-1.2-mile long sites on five streams in southwestern Wisconsin sampled annually from 1989 through 2005 (Lyons 2006a). The third, termed the "non-wadable spatial variation" (NSV) dataset, had miniboom shocker data from 67 non-wadable one-mile-long sites on 10 rivers located throughout the state and surveyed once each between 1996 and 1999 (Lyons et al. 2001). The fourth, termed the "non-wadable temporal variation" (NTV) dataset, had miniboom data from 10 non-wadable one-mile-long sites on the Lower Wisconsin River sampled annually from 1999 through 2006 (Lyons 2006b) and three non-wadable one-mile sites on the Menominee River and one non-wadable one-mile site on the St Croix River each sampled annually from 1996 through 1998 (Lyons 2004). All of the sites in these four datasets were classified as "least-impacted"; that is they were thought to have relatively low levels of human impacts (including angler harvest), and smallmouth bass populations were believed to be relatively close to their potential (i.e., maximum abundance and size structure given current landscape conditions). The two spatial variation datasets were used to compare abundance and size structure among stream/river classes and to generate expected abundance and size structure values for each class. The two temporal variation datasets were used to quantify the variation among samples within individual sites and to estimate the number of samples necessary to detect changes in smallmouth bass abundance and size structure.

STREAM AND RIVER CLASSIFICATION

The classification scheme was developed primarily from published research on the classification of Wisconsin's warmwater streams and rivers based on fish communities in general and smallmouth bass in particular. These studies, involving over 1,000 different stream and river reaches, have identified four broad-scale factors, listed here in order of importance, that in large part determine the occurrence, abundance, and size structure (and hence fishery potential) of smallmouth bass in Wisconsin streams and rivers:

1) Stream size (drainage area, stream order, flow, width, depth)

2) Summer water temperature (maximum, average)

3) Gradient (velocity, substrate, and channel morphometry)

4) Location in state (climate and geology)

5) Land cover and land use (especially forest, agriculture, and urbanization)

The first four factors are primarily “natural” and determine the potential (i.e., maximum possible) smallmouth population a particular stream or river can support in the absence of human influences, although clearly human activities have modified stream flow, temperature, gradient, and climate in many areas of the state. The fifth factor, human land use, helps determine actual population status, and often prevents a stream or river from reaching its full fishery potential.

Smallmouth bass in Wisconsin occur over a wide range of stream sizes, including the largest rivers in the state, but normally avoid relatively small streams (Forbes 1985; Lyons et al., 1988, 2000, 2001; Lyons 1991, Lyons and Kanehl 1993; Wang et al., 2003). For purposes of classification, the committee broke streams and rivers containing smallmouth bass into two categories, wadable and non-wadable, reflecting fundamental differences in sampling procedures necessary to characterize the smallmouth bass population in each (Lyons and Kanehl 1993; Lyons et al., 2001; Weigel et al., 2006a). Wadable stream and river reaches typically have drainage areas of less than 500 square miles (sqm) (usually less than 350 sqm), are less than 6th order (at the 1:24,000 scale), and have long-term mean annual flows less than 300 cubic feet per second (cfs), mean widths less than 175 ft (usually less than 120 ft), and pool depths that average less than 4 ft (although maxima may be much greater). Non-wadable rivers are generally larger than these threshold values and have been previously defined for the purposes of the baseline monitoring program (B. Weigel and J. Lyons, WDNR Fish Research, unpublished data). Many river reaches with size values close to the thresholds cannot be easily categorized as strictly wadable or non-wadable; they may have wadable stretches intermingled with non-wadable stretches within the same reach or may be wadable during relatively dry years but non-wadable during relatively wet years.

Smallmouth bass occur in all sizes of non-wadable rivers but are absent from many wadable streams (Lyons 1989, 1991, 1996; Lyons et al. 1988, 2001). Smallmouth bass are usually not found in streams with drainage areas less than 20 sqm, stream order less than 2, mean annual flows less than 10 cubic feet per second (cfs), mean width less than 15 ft, and mean pool depths depth less than 2 ft. Streams only slightly larger than these thresholds typically do not have a fully developed smallmouth bass population, as they are dominated by small juveniles and lack adults, except perhaps briefly during spring spawning (Forbes 1989; Lyons and Kanehl 1993, 2002). These streams, which we term "nursery streams", usually cannot support a fishery directly, but the young they contain may be critical to the maintenance of fisheries in larger stream reaches or lakes further downstream. In general, nursery streams have drainage areas of 20-50 sqm, range from the largest 2nd to the smallest 4th order, have mean annual flows from 10-30 cfs, mean widths from 15-40 ft, and pools that average 2-3 ft deep. Some streams with substantial larger drainage areas and widths may nonetheless also be classified as nursery streams if the geology and soils of their watershed keep their flow and maximum depth within the nursery range. Such larger streams may have many juvenile smallmouth bass but few adults and thus little direct fishery potential (J. Lyons, WDNR Fish Research, unpublished data).

Wadable streams larger than the nursery thresholds are capable of supporting a fully developed smallmouth bass population and associated fishery (Forbes 1985, 1989; Lyons and Kanehl 1993; Lyons et al., 1996; Mason et al., 1993). These "wadable warmwater" streams typically have drainage areas from 50-500 sqm, are 4th-5th order, have mean annual flows of 30-300 cfs, mean widths of 40-175 ft, and mean pool depths of 3-4 ft.

Water temperature limits the distribution and abundance of smallmouth bass in streams. Essentially, all non-wadable rivers are warm enough for fully developed smallmouth bass populations, but many wadable streams are not (Lyons 1989, 1996; Lyons et al., 2001). Although smallmouth bass can tolerate water temperatures down to freezing during the winter, streams that remain cold during the summer hamper smallmouth bass spawning and greatly reduce growth and survival of larvae and juveniles (Lyons 1997). True coldwater streams, with maximum daily mean water temperatures of 70 F or less, only rarely contain smallmouth bass (Lyons et al., 1996; Lyons 1997). "Coolwater" streams, with maximum daily mean water temperatures of 70-77 F, often have smallmouth bass, but the population is usually not fully developed. Reproduction and recruitment is typically limited and erratic because of temperature constraints on spawning and early growth and survival, and very large adults are usually relatively scarce because of slow growth. (Lyons 1997). Nonetheless a fishable population may be present, often because of migration from other warmer waters, consisting mainly of small to medium-sized adults (Forbes 1985; J. Lyons, WDNR Fish Research, unpublished data).

Gradient influences occurrence and abundance of smallmouth bass in both wadable streams and non-wadable rivers. Non-wadable rivers with a relatively high gradient, more than 3.1 ft mile, usually have a relatively high proportion (>10%) of their substrate as rubble/cobble or boulder and have the potential to support higher densities of smallmouth bass than non-wadable rivers with lower gradients and less rubble/cobble substrate (Lyons 1991, 2004, 2005a, 2005b; Weigel et al., 2006b). The higher-gradient "coarse-substrate" rivers are usually at the smaller end of the non-wadable river size spectrum and often change to lower-gradient "fine-substrate" rivers as they get larger.

Among wadable streams, many waters have a gradient too low to support a smallmouth bass population. Streams with gradients less that 4.2 ft/mile usually lack adequate pool-riffle development and rocky substrate to support smallmouth bass populations (Lyons et al., 1989; Lyons 1989, 1991, 1996).

Smallmouth bass are ubiquitous in Wisconsin, and no part of the state lacks the species (Lyons et al., 2000). However, differences in climate and geology across the state create inherent regional differences in the length and suitability of the growing season and in basic aquatic productivity, suggesting that there might be regional differences in the potential abundance, size structure, and growth rate of smallmouth bass populations (Forbes 1985; Lyons and Kanehl 1993; Lyons et al., 2001). Based on previous studies, the most likely differences would occur between streams in the northern third of the state and those located further south (Lyons 1989, 1996; Lyons and Kanehl 1993; Lyons et al., 2001; Weigel et al., 2006b).

CLASSIFICATION

From the above summary of the literature, a classification of Wisconsin's streams and rivers can be proposed with 14 categories, 10 of which have the potential to support a smallmouth bass population (Table 1). The classification recognizes five smallmouth bass stream/river types: wadable warmwater, wadable coolwater, wadable nursery, non-wadable coarse-substrate, and non-wadable fine-substrate, in each of two regions, north and south. The remaining four categories encompass the many wadable streams in the state that are too cold, too small, or have too low a gradient to have the inherent capability to support a smallmouth bass population. All non-wadable rivers in the state have the potential to support a smallmouth bass population.

The WSV and NSV datasets were used to test whether this proposed classification explained significant amounts of the variation in smallmouth bass abundance and age/size structure among stream sites. Catch-per-mile data were first log transformed for three different nested age/size categories, all fish age 1 or older ("age-1"), all fish 8 inches or larger ("8-inch"), and all fish 14 inches or larger ("14-inch"). The log transformation reduced the influence of a few unusually large values and created a more normal distribution of values to satisfy assumptions required for parametric statistical tests. Two-way analyses of variance (ANOVA) were ran with abundance as the dependent variable and stream type (wadable warmwater, wadable coolwater, wadable nursery for the WSV dataset, non-wadable fine-substrate and non-wadable coarse-substrate for the NSV dataset) and region (north versus south) as main effects and including the stream type-region interaction. Duncan multiple range tests were used to compare values among stream/river classes.

The ANOVAs indicated that there were statistically significant differences ($P < 0.05$) in smallmouth bass catch-per-mile between stream types and regions (Table 2). For wadable streams, the wadable warmwater class had significantly greater numbers of smallmouth bass than either the wadable coolwater or the wadable nursery classes for all three size/age categories (Age-1: $F = 7.98$; P , 0.0001; 8-inch: $F = 6.93$; $P < 0.0001$; 14-inch: $F = 2.73$; $P = 0.0320$). The wadable nursery and coolwater classes did not differ significantly from each other. For age-1 fish, southern streams had a significantly higher CPE than northern streams, but there were no regional differences in CPE for 8-inch and 14-inch fish.

For non-wadable streams, there were significant differences in CPE between coarse- and fine-substrate rivers and the northern and southern regions for all three age/size categories (Age-1: F = 3.65; P = 0.0172; 8-inch: F = 3.59; P = 0.0183; 14-inch: F = 5.04; P = 0.0034). Coarse-substrate rivers tended to have higher CPE than fine-substrate rivers and southern

Table 1 Classification of the inherent smallmouth bass fishery potential of Wisconsin streams and rivers with the physical criteria that define each class. Northern refers to the northern third of the state; southern to the remainder.

Stream class	Drainage area (square miles)	Mean annual flow (cfs)	Mean pool depth (ft)	Maximum daily mean water temp. (F)	Gradient (ft/mile)
Have the potential for a smallmouth bass population to be present					
Northern non-wadable fine substrate	> 500	> 300	> 4	> 77	< 3.1
Northern non-wadable coarse substrate	> 500	> 300	> 4	> 77	> 3.1
Northern wadable warmwater	50-500	30-300	3-4	> 77	> 4.2
Northern wadable coolwater	50-500	30-300	3-4	70-77	> 4.2
Northern wadable nursery	20-50[1]	10-30	2-3	> 77	> 4.2
Southern non-wadable fine substrate	> 500	> 300	> 4	> 77	< 3.1
Southern non-wadable coarse substrate	> 500	> 300	> 4	> 77	> 3.1
Southern wadable warmwater	50-500	30-300	3-4	> 77	> 4.2
Southern wadable coolwater	50-500	30-300	3-4	70-77	> 4.2
Southern wadable nursery	20-50[1]	10-30	2-3	> 77	> 4.2
Do not have the potential for a smallmouth bass population to be present					
Wadable coldwater	< 500	< 300	< 4	< 70	Any
Wadable warmwater headwaters	< 20	< 10	< 2	> 77	Any
Wadable coolwater headwaters	< 20	< 10	< 2	70-77	Any
Wadable low-gradient	20-500	10-300	2-4	> 70	< 4.2

[1]A stream can still be classified as wadable nursery if the drainage area is greater than 20-50 sqm but mean annual flow is 10-30 cfs and mean pool depth is 2-3 ft.

Table 2 Summary statistics for the within-class distribution of smallmouth bass catch per effort (CPE; number per mile of stream length) and relative stock density (RSD; %) among least-impacted sites from the two spatial-variation datasets. Age-1 refers to all fish age 1 or older, 8-inch to all fish 8 inches or larger, and 14-inch to all fish 14 inches or larger. N = number of sites; Min = minimum value, and Max = maximum value. The 50th percentile value is equivalent to the median value. N. = northern region and S. = southern region.

Stream class	Population metric	Percentile						
		N	Min	25th	50th	75th	Max	Mean
Non-wadable rivers (NSV dataset)								
Northern fine substrate	Age-1 CPE	12	0.0	1.5	2.5	5.0	16.0	3.9
	8-inch CPE	12	0.0	0.5	1.5	2.0	5.0	1.6
	14-inch CPE	12	0.0	0.0	0.0	0.5	1.0	0.3
	RSD	9	0	0	0	20	50	13
Northern coarse substrate	Age-1 CPE	13	0.0	2.0	5.0	9.0	27.0	7.7
	8-inch CPE	13	0.0	1.0	3.0	5.0	24.0	4.9
	14-inch CPE	13	0.0	0.0	0.0	1.0	6.0	1.1
	RSD	11	0	0	0	33	50	14
Southern fine substrate	Age-1 CPE	38	1.0	3.0	7.0	9.0	34.0	7.3
	8-inch CPE	38	0.0	2.0	4.0	6.0	20.0	4.3
	14-inch CPE	38	0.0	0.0	1.0	2.0	6.0	1.4
	RSD	35	0	8	30	57	100	38
Southern coarse substrate	Age-1 CPE	4	10.0	10.0	11.0	32.0	52.0	21.0
	8-inch CPE	4	3.0	5.0	7.0	9.0	11.0	7.0
	14-inch CPE	4	1.0	2.0	3.0	3.0	3.0	2.5
	RSD	4	27	30	38	43	43	37
Wadable streams and rivers (WSV dataset)								
N. wadable warmwater	Age-1 CPE	8	6.4	20.9	29.0	86.2	285.0	70.4
	8-inch CPE	8	4.8	7.2	19.3	46.7	173.9	40.7
	14-inch CPE	8	0.0	0.0	0.0	1.6	3.2	0.8
	RSD	8	0	0	0	2	13	2
N. wadable coolwater	Age-1 CPE	5	0.0	4.8	6.4	14.5	19.3	9.0
	8-inch CPE	5	0.0	0.0	1.6	3.2	12.9	3.5
	14-inch CPE	5	0.0	0.0	0.0	0.0	0.0	0.0
	RSD	3	0	0	0	0	0	0
Northern wadable nursery	Age-1 CPE	2	0.0	0.0	0.8	1.6	1.6	0.8
	8-inch CPE	2	0.0	0.0	0.8	1.6	1.6	0.8
	14-inch CPE	2	0.0	0.0	0.0	0.0	0.0	0.0
	RSD	1	0	0	0	0	0	0
S. wadable warmwater	Age-1 CPE	21	9.7	25.8	51.5	109.5	978.9	119.1
	8-inch CPE	21	3.2	8.1	17.7	49.9	392.8	49.0
	14-inch CPE	21	0.0	0.0	1.6	3.2	45.1	6.3
	RSD	21	0	0	3	15	60	11
S. wadable coolwater	Age-1 CPE	7	0.0	1.6	6.4	8.1	12.9	5.8
	8-inch CPE	7	0.0	0.0	1.6	3.2	3.2	1.6
	14-inch CPE	7	0.0	0.0	0.0	0.0	1.6	0.2
	RSD	4	0	0	0	25	50	13
Southern wadable nursery	Age-1 CPE	5	0.0	32.2	45.1	59.6	183.5	64.1
	8-inch CPE	5	0.0	0.0	16.1	32.2	66.0	22.9
	14-inch CPE	5	0.0	0.0	0.0	0.0	0.0	0.0
	RSD	3	0	0	0	0	0	0

rivers tended to have higher CPE than northern rivers (Table 2).

At present, the smallmouth bass classification has not yet been applied to the streams and rivers of the state. However, existing inventories of known smallmouth bass waters (WDNR 1968; Forbes 1985), coupled with results from an ongoing GIS-based computer modeling study to estimate

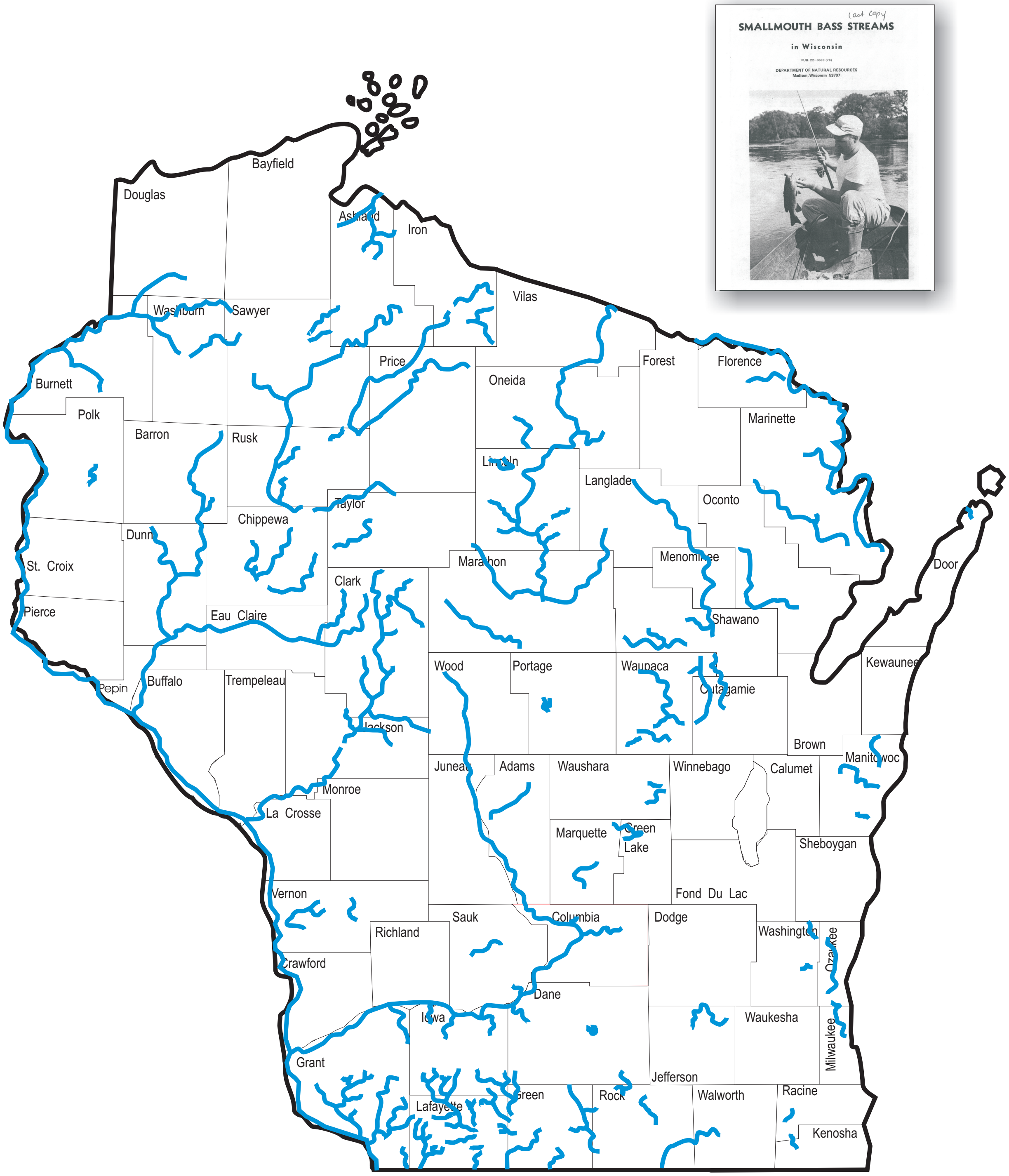

Figure 1. Distribution of smallmouth bass streams and rivers in Wisconsin. (taken from the 1978 publication *Smallmouth Bass Streams of Wisconsin)*.

the fishery potential of Wisconsin streams and rivers that provides drainage area, estimated flow, estimated maximum temperature, and gradient for all stream and river reaches in the state (Lyons and Mitro 2006), make application and mapping of the classification relatively straightforward and rapid.

Human land-use in the watershed and riparian areas of streams and rivers can alter smallmouth bass populations (Forbes 1989; Lyons et al., 1989; Mason et al., 1993; Wang et al., 1997, 2003; Wang and Lyons 2002). Intensive agriculture and urbanization are responsible for the decline of many smallmouth bass populations, particularly in southern Wisconsin. Inappropriate land-uses, along with pollution, direct habitat modifications (e.g., dams, dredging, flow alterations), and angling over-harvest, are the main factors that prevent smallmouth bass populations from achieving the potential of their particular stream or river class.

RECOMMENDED SAMPLING

The committee concluded that two types of data, abundance and size/age structure, are needed for effective management of smallmouth bass in streams and rivers. Abundance can be estimated either through catch-per-effort (CPE) or population estimate parameters. Based on previous studies, CPE data expressed as the catch per length of stream or river sampled, rather than surface area or duration of sampling, are recommended as the standard to assess abundance (Lyons and Kanehl 1993; Lyons 2004). Catch-per-effort data, although often relatively imprecise (see below), accurately track true fish numbers, as demonstrated in direct experiments (Lyons and Kanehl 1993; Simonson and Lyons 1995) and in evaluations of smallmouth bass fishery regulations (Lyons et al., 1996) and smallmouth bass abundance relative to human habitat modifications (Kanehl et al., 1997; Lyons 2004, 2005a, 2005b; Weigel et al., 2006a).

Population estimates provide a more precise measure of abundance, but may not be as accurate or cost-effective as CPE data. An examination of existing population estimates by Lyons and Kanehl (1993) indicated that mark-recapture population estimates were highly biased and inaccurate because of apparent changes in smallmouth bass behavior following marking. Depletion (=removal) population estimates were more accurate but required substantially more time and effort (> 5 times) than CPE data in wadable streams, making them cost prohibitive in most cases. Population estimates were completely impractical in non-wadable rivers because of the huge amounts of labor involved and substantial biases due to fish movements (Lyons 2006b).

Size/age structure is determined through direct measurement of length and weight from sampled fish and through estimation of age from hard structures, such as scales or fin spines, taken from these fish. Length is the easiest of the three types of data to collect, can be used to approximate weight and age, and is essential in most management contexts as it is the basis for many fishery regulations (i.e., length limits). The committee recommended that collection of length data from all captured smallmouth bass be mandatory, but that weight and age data could be collected at the discretion of the biologist. Length data should be summarized as catch per ½ inch length interval in a length frequency histogram and from there summarized as Proportional Stock Density (PSD) and Relative Stock Density (RSD), ratios of the total catch of relatively large fish to the total catch of all medium and large fish (Anderson and Neumann 1996). For smallmouth bass, PSD has been defined as the ratio of fish 11 inches ("preferred size") or greater to fish greater than 7 inches ("stock size"), whereas RSD has a fish length in the numerator that is specified by the user. The committee recommends using a variant of RSD with a numerator of 14 inches or greater and a denominator of 8 inches or greater because 14 inches is the length for legal angler harvest in nearly all smallmouth bass waters in Wisconsin and 8 inches is the typical size at first maturity (i.e., adulthood) for smallmouth bass in Wisconsin streams and rivers (Forbes 1989; Lyons and Kanehl 1993).

Stream and river smallmouth bass in Wisconsin are captured most efficiently by electrofishing. Recommendations for sampling techniques are based on previously published analyses of electrofishing performance (Lyons 1992; Lyons and Kanehl 1993; Simonson and Lyons 1995; Lyons et al., 2001). In non-wadable rivers, a single standard WDNR pulsed-DC mini-boom shocker with one netter is recommended (Lyons et al., 2001; Lyons 2004, 2006b; Weigel et al., 2006a). Shocking should proceed in a downstream direction along one shoreline during daylight. In coarse-substrate rivers with rapids, an inflatable raft mini-boom shocker can be substituted for the standard aluminum solid-hull version. In wadable streams and rivers, one or more standard WDNR DC stream ("tow-barge") shockers with three anodes will be most effective (Lyons 1992, 2006a; Lyons and Kanehl 1993; Simonson and Lyons 1995). Shocking should proceed in an upstream direction over the entire width of the stream channel during daylight. One shocker is recommended for streams less 60 ft wide, two shockers for streams 60-89 ft wide, and three shockers for streams 90 ft or wider. For both wadable and non-wadable streams and rivers, shocking will be most efficient and representative during summer months at baseflow (Lyons and Kanehl 1993; Lyons 2004).

Sampling effort for stream and river shocking is best expressed as the length of stream channel sampled (Lyons 1992; Lyons and Kanehl 1993; Lyons et al., 2001). Previous studies indicated that a sampling length of 40 times the mean stream width was the minimum appropriate to characterize the fish community of a wadable stream site but that longer lengths would often be necessary to achieve an adequate sample size for smallmouth bass length-frequency analyses (Lyons 1992; Lyons and Kanehl 1993). Based on a consensus among committee members that at minimum of 16-25 fish were needed for a meaningful length analysis, a fixed distance of 0.5 miles (2640 ft) was recommended for wadable streams. At this distance, based on an analysis of the distribution of CPE values within the WSV dataset (Table 2), the probabilities that at least 16 age-1 smallmouth bass will be collected are approximately 67% for southern warmwater, 75% for southern nursery, 0% for southern coolwater, 50% for northern warmwater, 0% for northern nursery, and 0% for northern coolwater streams. These values are for least-impacted streams where smallmouth bass populations have not been depressed by human activities, and in impacted streams, where populations are lower, the probabilities would be reduced. Obviously, increasing the sampling length beyond 0.5 miles would improve the chances that 16 smallmouth bass would be collected, but the committee felt that the benefits of longer lengths were offset by the increased time and labor required and the ultimately the smaller number of sites that could be sampled within any given time period.

For non-wadable rivers, the minimum sampling distance necessary to characterize the fish community is one mile

(Lyons et al. 2001), and this distance has been the minimum standard for WDNR baseline monitoring for the last five years. The committee agreed that this distance should be retained as a minimum for smallmouth bass in rivers, with the option to substantially increase sampling length depending on smallmouth bass CPE and the necessity of a sample of 16 fish for length analyses. In large rivers, particularly the fine-substrate class, smallmouth bass are highly patchy in distribution but generally present at low densities (Lyons 2004, 2005a, 2006b; Weigel et al. 2006a), and assuring a catch of at least 16 age-1 smallmouth bass usually requires a very long station. From an analysis of the NSV dataset (Table 2), with a station length of one mile, the probability of collecting 16 age-1 smallmouth bass would be approximately 45% for southern coarse-substrate, 13% for southern fine-substrate, 8% for northern coarse-substrate, and 8% for northern fine-substrate rivers. To have a 50% chance of catching at least 16 smallmouth bass would require sampling lengths of 1.3 miles for southern coarse-substrate, 2.3 miles for southern fine-substrate, 3.2 miles for northern coarse substrate, and 6.5 miles for northern fine-substrate rivers.

The precision of the CPE and RSD data determines how large a change in a smallmouth bass population must occur before it will be likely to be detected by sampling or, conversely, how many samples must be taken to have a reasonable chance of detecting a given change in the population. Sampling precision is estimated from the variability in CPE and RSD among different sampling sites (spatial variation) and among samples taken at different times at individual sites (temporal variation). Thus, spatial variation in CPE and RSD represents inherent differences in potential and sampling effectiveness among classes and among waters within classes, and temporal variation represents typical year-to-year fluctuations in CPE and RSD owing to natural environmental variation, primarily climate, and variation in sampling effectiveness.

For assessing responses of smallmouth bass populations to human impacts (e.g., riparian land-use changes) or management activities (e.g., changes in fishing regulations), as well as to better understand general trends in smallmouth bass abundance and age/size structure, a variant of the before-after-control-impact design (BACI; Underwood 1994) is recommended. For this approach, multiple independent sites, some of which have the impact or management activity and others of which do not ("control"), are sampled before and after the impact or activity occurs. Comparisons are made between time periods (i.e., before and after activity in question) for each stream site, and the different streams act as "blocks" (in a statistical sense) to provide replication and to account for variation in response among sites. The key comparison is how the impact sites change before and after relative to the control sites. If the change at the impact sites is large relative to any change at the control sites (which may occur due to a natural population fluctuation, for example), then it can be concluded that the impact or management activity had a meaningful effect. In a statistical sense, you test for a significant interaction between the type of stream (impact vs control) and time period (before vs. after).

The statistical power of the BACI design, which is the ability to detect a real change in the parameter of interest, is high relative to other sampling designs, but can be complicated to determine when there are multiple years of before and after data (Osenberg et al., 1994). For the simple case where there is only one sample per site from before the impact/activity and one from afterwards and the response is expressed as the difference between the before and after period, it is possible to use a standard t-test power analysis formula to determine how many different pairs of sites (i.e., one control and one impact) are needed to have a known probability of detecting a response of a given magnitude. This determination assumes no temporal congruence among sites, which is simplistic given that smallmouth bass populations often fluctuate in synchrony over large geographic areas because of climate induced regional variation in reproductive success (Mason et al., 1993; Lyons et al., 1996; Lyons 2006a). However, positive synchrony in natural population fluctuations among control and impact sites reduces spatial variation and makes population changes easier to detect, so the simplified power analysis may be conservative for many situations.

The t-test statistical power formula is:

N = (2s2/ä2) (tá,í + tÂ(1), õ)2

where N is the number of pairs of sites needed, s is the standard deviation of the variation among years (i.e., temporal variation) for individual sites, ä is size of the effect of interest, i.e., the magnitude of the difference between before and after values for impact sites and before and after values for the control sites, and tá,í and tÂ(1), í are t-statistic values for specified probabilities, á referring to the probability of type I error, that is, concluding that there has been a change when in fact one has not taken place, set at 5% for this analysis, and Â referring to the probability of type II error, that is, concluding that there has been no change when in fact one has occurred, set at 20% for this analysis, and í is the degrees of freedom for each t statistic (number of pairs of sites minus one).

Temporal variation was estimated from analyses of the WTV and NTV datasets. Mean and standard deviation was calculated for each individual site across all years for each of the three CPE values and for RSD. Where there was more than one site per stream class, the mean of the means and the standard deviations were determined for all sites within each class. Values are given in Table 3.

Using the power formula, estimated temporal variation, and a relative effect size of either 50% (i.e., the impact sites increased by 50% relative to the control sites from the before to the after sample), 100% or 200%, the sample size necessary to detect the effect for each of the stream classes that had any temporal variation data available was determined (Table 4). The smaller the size of the effect, the more pairs of sites were needed to have a reasonable chance of detecting a change. However, the number of pairs needed dropped rapidly as the size of the effect increased. For a 50% change, 22-106 pairs were needed, but for a 100% change, 3-27 were required, and for a 200% change, only 2-10 were necessary. Because the standard deviations of the 14-inch CPE and RSD categories were higher relative to their mean values than the those for the Age-1 and 8-inch CPE categories, detecting a given change in 14-inch CPE and RSD values required substantially more pairs of sites.

QUANTITATIVE ASSESSMENT CRITERIA

Based on analyses of the WSV and NSV datasets, criteria have been proposed for assessing the status of smallmouth bass populations in Wisconsin's streams and rivers (Table 5). Each stream class has its own criteria, and they are derived from data in Table 2. The 25-75% percentiles of the distribution of CPE and RSD values from the

Table 3 Means and standard deviations of CPE (number per mile) and RSD (%) values across years for smallmouth bass at selected stream and river sites.

Site	Years	Mean/Standard deviation			
		Age-1 CPE	8-inch CPE	14-inch CPE	RSD
Southern wadable warmwater streams (WTV dataset)					
Ames Branch	1991-2005	4.0/2.8	2.4/1.4	0.2/0.2	7/6
Galena River	1990-2005	8.3/4.8	4.6/2.1	0.9/0.7	20/11
Little Platte River	1990-2005	8.6/5.0	4.3/2.0	0.6/0.3	17/10
Rattlesnake Creek	1990-2005	6.7/3.2	3.5/1.1	0.4/0.2	13/6
Mean		6.9/4.0	3.7/1.7	0.5/0.4	14/8
Southern wadable nursery streams (WTV dataset)					
Mineral Point Branch	1989-2005	5.5/4.1	2.3/1.2	0.1/0.1	7/7
Southern non-wadable fine-substrate rivers (NTV dataset)					
Wisconsin R. (4.4)	1999-2006	3.3/2.1	1.8/0.9	0.9/0.8	50/41
Wisconsin R. (16.4)	1999-2006	2.2/1.1	1.3/1.3	0.4/0.7	23/32
Wisconsin R. (17.6)	1999-2006	3.4/2.1	2.1/2.1	0.4/0.8	23/43
Wisconsin R. (36.5)	1999-2006	15.4/9.7	8.3/6.2	1.4/1.8	17/21
Wisconsin R. (43.1)	1999-2006	10.0/5.1	7.0/3.1	1.8/1.2	26/21
Wisconsin R. (45.5)	1999-2006	16.3/6.5	9.1/3.4	2.3/1.8	25/20
Wisconsin R. (50.2)	1999-2006	4.0/2.6	2.6/2.5	0.6/0.9	12/16
Wisconsin R. (67.9)	1999-2006	3.8/1.5	2.6/1.3	0.9/0.8	32/35
Wisconsin R. (75.9)	1999-2006	5.5/3.2	3.6/2.2	1.5/1.4	38/26
Wisconsin R. (89.9)	1999-2006	17.3/7.1	8.5/5.0	1.5/1.2	17/9
Mean		8.1/4.1	4.7/2.8	1.2/1.1	26/26
Northern non-wadable fine-substrate rivers (NTV dataset)					
St. Croix River	1996-1998	4.7/0.6	1.3/0.6	0/0	0/0
Northern non-wadable coarse-substrate rivers (NTV dataset)					
Menominee R. (QF2)	1996-1998	15.3/19.7	3.7/2.5	0.7/1.2	11/19
Menominee R. (SF1)	1996-1998	10.7/5.0	8.0/6.6	3.3/3.1	32/29
Menominee R. (SF2)	1996-1998	19.3/8.0	16.7/7.5	2.7/1.5	16/7
Mean		15.1/10.9	9.5/5.5	2.2/1.9	20/18

WSV and NSV datasets, rounded up to the nearest whole number per mile, determine the criteria and are considered acceptable ranges for smallmouth bass populations. For the wadable nursery class, criteria are not provided for the 8-inch CPE, 14-inch CPE, and RSD population metrics. By definition, nursery streams do not have the capability to support a fully developed population of adult (i.e., 8 inches or larger) smallmouth bass, so it is inappropriate to assess such streams based on adult abundance and size structure. Similarly, for the wadable coolwater classes, criteria are not provided for the 14-inch CPE and RSD metrics, as coolwater streams inherently tend to lack larger adults, and for the age-1 CPE metric, as reproduction is often limited by cold water temperatures.

DISCUSSION

The committee has developed an easily understood and applied classification of

Table 4 Number of pairs of sites (impact site plus control site) necessary in a Before-After-Control-Impact (BACI) experimental design with one before sample and one after sample in order to detect a relative change in smallmouth bass population CPE (number/mile) and RSD (%) of either 50% or 100% with a 5% chance of Type I error and a 20% chance of Type II error for different stream classes. A "" indicates that a calculation was not possible because of division by zero.

-- Stream class	Population metric	Number of pairs to detect change of 50%	100%	200%
Southern wadable warmwater	Age-1 CPE	36	8	3
	8-inch CPE	22	6	3
	14-inch CPE	68	17	4
	RSD	35	9	5
Southern wadable nursery	Age-1 CPE	59	15	5
	8-inch CPE	29	8	3
	14-inch CPE	106	27	8
	RSD	106	27	8
Southern non-wadable fine-substrate	Age-1 CPE	27	8	3
	8-inch CPE	38	10	4
	14-inch CPE	89	22	10
	RSD	106	27	8
Northern non-wadable fine-substrate	Age-1 CPE	4	3	2
	8-inch CPE	23	7	3
	14-inch CPE	--	--	--
	RSD	--	--	--
Northern non-wadable coarse-substrate	Age-1 CPE	55	14	5
	8-inch CPE	36	10	4
	14-inch CPE	79	20	6
	RSD	86	22	6

Wisconsin's smallmouth bass streams and rivers that accurately accounts for much of the inherent variation in smallmouth bass populations and fishery potential among waters. Stream size, summer temperature, and location in the state are the three environmental factors that define classes. Statistical analyses of catch data from least-impacted streams and rivers indicate that each class is capable of supporting a significantly different abundance and size/age distribution of smallmouth bass. These differences are inherent to the class, and not the result of human impacts such as pollution, habitat modifications, or over-harvest. Because the classification is based on environmental factors that are known or have been modeled for all waters in the state, the process of classifying all flowing waters in the state is practical and straightforward.

Because the classification is based on inherent "natural" factors, data from the least-impacted sites can be used to estimate the expected abundances and size distributions of smallmouth bass in each class. These estimates (Table 5) provide an objective framework for determining if a particular stream or river is meeting its potential. Field data on smallmouth bass CPE and RSD from a stream in a particular class can be compared with the appropriate expectations to determine the current status of the smallmouth bass population. Significant negative deviations from these expectations indicate where smallmouth bass populations are below their potential and in need of restoration. Further investigations of other factors, including watershed and riparian land use, can help explain why the population is below expectations and suggest management

Table 5. Population criteria for assessing smallmouth bass in Wisconsin's streams and rivers. CPE is expressed as number per mile and RSD as %. NA= not applicable.

Stream class	Population metric	Assessment criteria: Below	Acceptable	Exceptional
Non-wadable rivers				
Northern fine substrate	Age-1 CPE	<2	2-5	>5
	8-inch CPE	<1	1-2	>2
	14-inch CPE	<1	1	>1
	RSD	<20	20-40	>40
Northern coarse substrate	Age-1 CPE	<2	2-9	>9
	8-inch CPE	<1	1-5	>5
	14-inch CPE	<1	1	>1
	RSD	<20	20-33	>33
Southern fine substrate	Age-1 CPE	<3	3-9	>9
	8-inch CPE	<2	2-6	>6
	14-inch CPE	<1	1-2	>2
	RSD	<20	20-60	>60
Southern coarse substrate	Age-1 CPE	<10	10-32	>32
	8-inch CPE	<5	5-9	>9
	14-inch CPE	<2	2-3	>3
	RSD	<30	30-50	>50
Wadable streams and rivers				
N. wadable warmwater	Age-1 CPE	<20	20-90	>90
	8-inch CPE	<7	7-50	>50
	14-inch CPE	<1	1-3	>3
	RSD	<5	5-50	>50
N. wadable coolwater	Age-1 CPE	NA	NA	NA
	8-inch CPE	<2	2-4	>4
	14-inch CPE	NA	NA	NA
	RSD	NA	NA	NA
Northern wadable nursery	Age-1 CPE	<2	2-4	>4
	8-inch CPE	NA	NA	NA
	14-inch CPE	NA	NA	NA
	RSD	NA	NA	NA
S. wadable warmwater	Age-1 CPE	<25	25-110	>110
	8-inch CPE	<8	8-50	>50
	14-inch CPE	<2	2-4	>4
	RSD	<5	5-50	>50
S. wadable coolwater	Age-1 CPE	NA	NA	NA
	8-inch CPE	<2	2-4	>4
	14-inch CPE	NA	NA	NA
	RSD	NA	NA	NA
Southern wadable nursery	Age-1 CPE	<30	30-60	>60
	8-inch CPE	NA	NA	NA
	14-inch CPE	NA	NA	NA
	RSD	NA	NA	NA

strategies for restoration. Streams with CPE and RSD well above expectations represent unusually good smallmouth bass populations that may warrant special protection efforts.

Our results emphasize that smallmouth bass are a low-density species in Wisconsin's streams and rivers. Most CPE values are below 10 fish/mile, which is 50-100 times lower than CPE values for trout in least-impacted Wisconsin streams (J.

Lyons, WDNR Fish Research, unpublished data). Smallmouth bass larger than 14 inches are particularly scarce, with the majority of streams and rivers having fewer than two fish of this size per mile. Low densities require that sampling distances be relatively long, much greater than lengths necessary to assess the overall fish community, if an adequate number of smallmouth bass are to be collected for age and length analyses. Low densities also imply that smallmouth bass may be particularly vulnerable to over-harvest in many settings, and that restrictive angling regulations are necessary.

Despite inherently low densities of smallmouth bass in streams and rivers, the classification and sampling recommendations developed here allow an objective evaluation of the response of smallmouth bass populations to human impacts and management activities. Because the CPE and RSD data are relatively imprecise (standard deviation typically 50-100% of mean value; Table 3), if the goal is to detect relatively subtle population responses, then large sample sizes are required, on the order of 50-200 sites (25-100 pairs) each sampled before and after the impact or activity of interest. Clearly such a sampling effort would require a large-scale coordinated project involving many different biologists. However, to detect more dramatic population responses, the sample sizes are much lower, on the order of 10-20 sites, a level of effort realistic for a single biologist to carry out. Because large smallmouth bass are less common and relatively more variable in abundance than smaller bass, efforts to evaluate management activities that focus on larger bass, such as trophy regulations, will require greater sampling effort than more general population evaluations.

ACKNOWLEDGEMENTS
Committee members Al Niebur, Dave Seibel, Bradd Sims, Dave Vetrano, Doug Welch, John Lyons, and Karl Scheidegger should be commended for their efforts. In particular, the team is indebted to John Lyons for his smallmouth bass and statistical analyses expertise. Paul Rasmussen and Brian Weigel provided many fruitful discussions and helpful comments on analyses and conclusions.

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APPENDIX 1

STREAM AND RIVER TYPES

Wisconsin streams and rivers that support significant smallmouth bass populations can be classified into the following five types:

1) Wadable warmwater A wadable stream with habitat suitable for a fishable population of adult smallmouth bass, including legal-sized (≥ 354 mm (14") fish. These streams are typically 4th to 6th order with watershed areas of 50-500 square miles (usually less than 350) and mean widths of 11-50 m (35-175 ft). Deeper pools often exceed 1.25 m (4 ft) and may have areas that are un-wadable, but at summer baseflow more than 67% of the surface area of pools and deep runs can be sampled effectively by wading. Maximum instantaneous summer water temperatures usually exceed 28 C (82.5 F), and maximum daily mean temperatures are 24-30 C (75-86 F). Stream gradient is high enough, usually more than 0.8 m/km (4.2 ft/mile), to produce at least some riffles or shallow rocky runs.


Jump River, Rusk Co.


Black River, Clark Co.

Wadable warmwater streams are common and widespread throughout much of the southern two-thirds of the state, particularly the extreme southwest. They also occur in the northern third, although there coolwater streams (see below) are more common. In regions that are particularly flat with fine-textured soils, many otherwise suitable warmwater streams may lack sufficient gradient or rocky substrate to produce good smallmouth bass habitat.

Examples of wadable warmwater smallmouth bass streams: The Galena River in Lafayette County, the Little Platte River and Rattlesnake Creek in Grant County, the Milwaukee River in Ozaukee and Washington counties, the Sheboygan River in Sheboygan County, the Black River in Clark County, the Big Rib River in

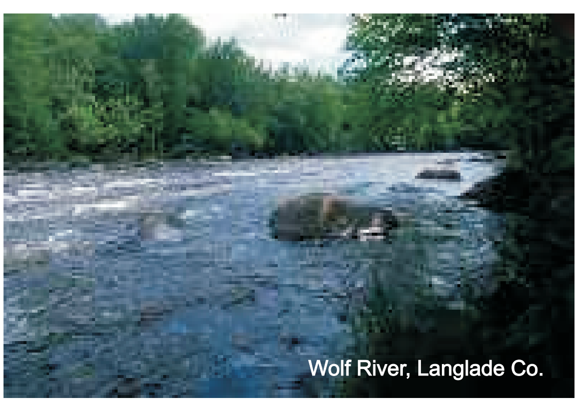

Otter Creek, Lafayette Co.

Marathon County, the Jump River in Rusk and Taylor counties, and the upper South Fork of the Flambeau River (above Fifield) in Price County.

2) Wadable coolwater A wadable stream with habitat suitable for smallmouth bass but summer water temperatures too cold to support a population as large as in a comparable warmwater stream. Maximum instantaneous summer water temperatures

Pecatonica River, Lafayette Co.

rarely exceed 26 C (79 F) and maximum daily mean temperatures are usually 20-25 C (70-77 F). Coolwater streams have a fishable population of adults (≥ age 3, ≥ 204 (8”) TL), at least during summer months, but they typically have relatively few legal-sized fish, perhaps because of slow growth.



Wolf River, Langlade Co.

Wadable coolwater streams are widespread, especially in the northern third of the state, and vary in their smallmouth bass characteristics. Some coolwater streams may have a permanent resident population and natural reproduction, whereas others have smallmouth bass only because of seasonal movements from nearby warmwater streams or lakes. Coolwater streams often comprise the lower reaches of trout streams, and trout and smallmouth bass may overlap in occurrence.

Examples of wadable coolwater smallmouth bass streams: The upper Grant

Namekagon River, Washburn Co.

River (above CTH A) in Grant County, the Wolf River in Langlade County, the Red River in Shawano County, the Namekagon River in Sawyer and Washburn counties, and the Brule River in Florence County.

3) Wadable nursery A warmwater stream too small and/or shallow to support a fishable population of adults, but capable of holding a significant number of juveniles. Adults may use the stream during the spawning period, but are otherwise scarce or absent, and their abundance does not necessarily indicate the quality of the stream. Most nursery streams are large 2nd order, 3rd order, and perhaps smaller 4th order, with watershed areas of 20-50 square miles. Mean width is usually less than 13 m (40 ft) and few if any pools have a


Roundtree Branch, Grant Co.

maximum depth of more than 1.25 m (4 ft). Gradient is usually greater than 1 m/km (5.3 ft/mile), and rocky riffles and shallow runs are common. A few much larger (4th and 5th order; 15-20 m (50-70 ft) wide) but consistently shallow and relatively high gradient streams may also be categorized as nursery streams. Invariably a nursery stream is the headwaters or a tributary of a larger stream or lake with a large smallmouth bass population.

Most wadable nursery streams occur in extreme southwestern Wisconsin, where small high-gradient warmwater streams


Pensaukee River, Oconto Co.

are common. Only a few occur elsewhere in the state, probably because most small streams are either too low gradient or have summer water temperatures too low to provide good smallmouth bass habitat.

Nursery streams in southwestern Wisconsin include: Pats Creek, Lafayette County, Boice Creek and Pigeon Creek, Grant County, and Mineral Point Branch, Iowa County. Examples from elsewhere are Wedges Creek (above Hwy 10) in Clark County, and the Branch River in Manitowoc County. A relatively large (5th order; 16+ m (53 ft) wide) but shallow (95% of stream surface area less than 1-m deep at summer baseflow) stream that qualifies as nursery water is the Pensaukee River in Oconto County, which empties into Green Bay.

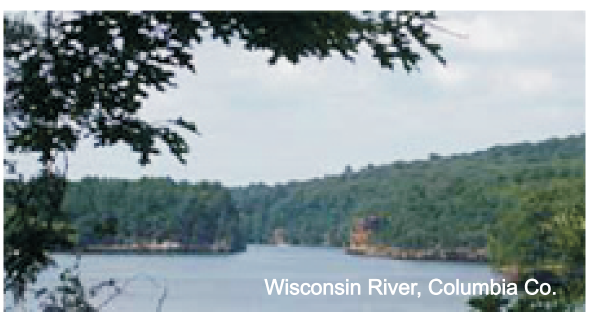
4) Non-wadable coarse-substrate A warmwater river with significant amounts of natural rubble/cobble and boulder


Wisconsin River, Marathon Co.

substrate. More than 10% and often more than 25% of the river surface area consists of habitats where the majority of the substrate is rubble/cobble or boulder (riffles or rapids and shallow runs). Typically these rivers have a largely upland riparian area and a relatively high gradient for a non-wadable river, usually above 0.6 m/km (3.1 ft/mile). They tend to be on the smaller end of the spectrum for non-wadable rivers, 4th-7th order with drainage areas of 300-3,000 square miles and mean widths of 30-100 m (100-330 ft). Coarse-substrate rivers typically shift to fine-substrate rivers (see below) once they exceed a certain size.

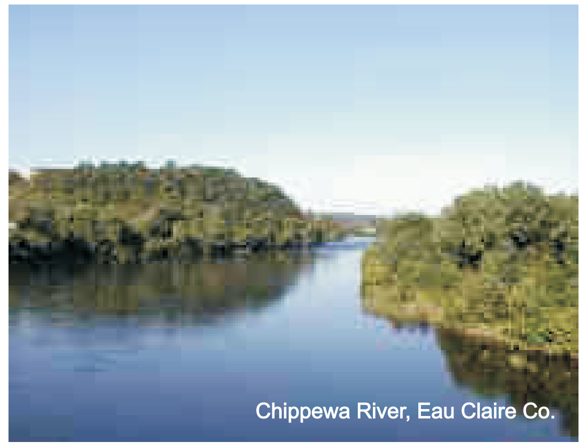
Coarse-substrate rivers occur throughout the state, but because of topography and geology are most common in the northern two-thirds. Examples (impounded reaches excluded) include the LaCrosse River just below Lake Neshonoc in LaCrosse County, the Embarrass River in Outagamie County, the Menominee River above Chalk Hill Reservoir in Marinette and Florence counties, the Wisconsin River in Marathon, Lincoln, and Oneida counties, the Flambeau River in Price, Sawyer, and Rusk counties, the Chippewa River in Sawyer and Rusk counties, and the St. Croix River in Douglas and Burnett counties.

5) Non-wadable fine-substrate A warmwater river dominated by natural



Wisconsin River, Columbia Co.

substrates of gravel, sand, silt, and/or clay. Less than 10% of the river surface area consists of habitats where the majority of the substrate is rubble/cobble or boulder, although these uncommon habitats are important for smallmouth bass spawning and recruitment. Fine-substrate rivers often have relatively wide and flat floodplains with predominantly lowland or wetland riparian areas. Gradients are less



Chippewa River, Eau Claire Co.

than 0.6 m/km (3.1 ft/mile) and are often only 0.2 m/km (1 ft/mile). Sizes vary greatly and include the largest rivers in the state, ranging from 4th-9th order with drainage areas of 300-30,000 square miles and mean widths of 30-800 m (100-2600 ft). Because large rocky substrate is uncommon in these rivers, fallen trees along the banks and large woody debris in the channel are the most important natural smallmouth bass habitats.

Fine-substrate rivers occur throughout the state but because of topography and geology are rare in the north. Examples (impounded reaches excluded) include the Rock River in Rock County, the Wisconsin River, in Juneau, Adams, Sauk, Columbia, Dane, Iowa, Richland, Crawford, and Grant counties, the Yellow River in Juneau County, the Black River in Jackson County, the Fox River in Winnebago County, the Chippewa River in Eau Claire, Dunn, Pepin, and Buffalo counties, the St. Croix River in Polk and St. Croix counties, the Wolf River in