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Assessing Channel Catfish Stocking Rates with Simple Growth Increment Indices

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Abstract.—Large fingerling (>175 mm total length) channel catfish *Ictalurus punctatus* are usually stocked to maintain put-grow-take channel catfish fisheries in small lakes and impoundments. Because these stockings are costly, stocking the appropriate number of fish is essential in minimizing costs and creating a desirable fishery. Appropriate stocking rates may vary among lakes due to differences in lake productivity, fishing and natural mortality of channel catfish, and other factors. Growth rate is responsive to the many processes that exist in lakes and is commonly density-dependent, making it a desirable parameter for assessing stocking rates. Two growth-increment indices were developed that compared size-specific growth increments within a population to statewide growth-increment percentiles for Missouri. These indices were used to determine responses in channel catfish growth rates in seven lakes where stocking rates had been either substantially reduced or increased. Sampling channel catfish populations after 3 years under the new stocking rate showed that growth increments and size structure did not substantially change. Both indices were correlated with growth increments and provided a way to assess growth relative to other populations. The lack of response of channel catfish populations to the new stocking rates suggests that these populations will not quickly respond to changes in stocking rate. The growth increment indices should assist managers in determining appropriate stocking rates and other management strategies.

Introduction

Put-grow-take fisheries for channel catfish *Ictalurus punctatus* are popular in many small lakes and impoundments (hereafter termed “lakes”) in the Midwestern and southern United States (Michaletz and Dillard 1999). Usually, stocking large fingerlings (>175 mm total length [TL]) is necessary to maintain these fisheries because small fingerlings are highly vulnerable to predators such as largemouth bass *Micropterus salmoides* (Storck and Newman 1988; Santucci et al. 1994). Because rearing and stocking large fingerlings is relatively expensive, stocking the appropriate number of fish is essential in minimizing costs and creating a desirable fishery. Overstocking can lead to poor growth and size structure of channel catfish (Mitzner 1999; Mosher 1999; Michaletz 2009), reduced prey abundance (Mitzner 1989; Michaletz et al. 2005), and reduced growth of sympatric fish species (Crance and McBay 1966; Mitzner 1989; Michaletz 2006a) while stocking too few fish may not create a desirable fishery. Determining the appropriate stocking rate is difficult because popu-

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lations among lakes may respond differently to the same stocking rate due to differences in lake productivity, fishing and natural mortality, and other factors (Michaletz 2009). Hence, stocking rates should be determined for individual lakes because a single stocking rate will not be appropriate for all lakes.

Various criteria have been used to determine stocking rates for individual lakes. Austen et al. (1997) assigned stocking rates to lakes based on the measured or anticipated angling effort directed toward channel catfish. Unfortunately, angling effort data are frequently not available for many small lakes, making this procedure difficult to commonly apply. Mitzner (1999) suggested that mean length and relative weight could be used to track populations over time and if these variables decreased to undesirable levels, stocking rates should be reduced. Mosher (1999) stated that stocking rates should be reduced if the mean length of stocked channel catfish after 1 year was less than 300 mm. Because relative weight is often not strongly related to growth (Gutreuter and Childress 1990; Michaletz 2009), and small mean length could be due to slow growth or high mortality, Michaletz (2009) proposed comparing growth increments of individual fish within a lake to a statewide standard for fish of the same initial length (back-calculated length at the beginning of the growing season) to determine the relative growth rate for the population. Growth rate is responsive to the many density-dependent and density-independent processes that exist in lakes, making it a desirable parameter for assessing stocking. Stocking rates could be reduced for slow-growing populations, whereas opportunity exists to increase stocking rates for fast-growing populations.

Comparing growth increments among fish with the same initial length is more appropriate than using mean length at age for stocked populations. Growth is more closely related to size than to age (Gerking and Raush 1979; Gutreuter 1987). In Missouri, while most stocked fingerlings exceed 200 mm TL, fingerlings of the same age can range widely in size from 125 to 450 mm TL (Michaletz 2009) and are stocked at different ages (either age 0 or age 1) depending upon which rearing facility raised them. In some cases, both age-0 and age-1 fish are stocked into the same lake within a year. Thus, comparing mean length at age among populations is inappropriate because length at age is highly variable and fish of the same age may have lived in the lakes for different amounts of time (Michaletz 2009). Michaletz (2009), like Putman et al. (1995) and Shoup et al. (2007), related the last growth increment to the initial length at the beginning of the growing season with linear regression. Growth increments could then be compared for fish of the same initial size across populations.

The objectives of this study were to develop growth increment indices that would compare growth increments for individual fish to a statewide standard, as Michaletz (2009) suggested, and then to apply these indices to a set of lakes where stocking rates changed to assess whether populations responded to these changes. Two potential indices were developed based on growth rates of channel catfish in small lakes with put-grow-take fisheries in Missouri, and the utility of these indices were compared. While factors other than density influence channel catfish growth, channel catfish abundance was significantly related to stocking rate and was the most important variable explaining differences in growth increments among populations in Missouri (Michaletz 2009). It is also a variable that managers can most easily manipulate by adjusting stocking rates. The use of an appropriate index should reduce the frequency of overstocking and understocking and enable fisheries managers to make more efficient use of a valuable hatchery product.

Developing the Growth Increment Indices

Growth increment indices were developed using initial total length–last growth increment linear regressions from 56 channel catfish populations in small lakes in Missouri that were sampled in the spring of 2003. Data from all but one of these populations were taken from Michaletz (2009), where at least 10 individuals were available to compute the regressions. The additional lake had been sampled in 2003 but was not reported in Michaletz (2009). Michaletz (2009) found that linear equations were appropriate for all sampled populations, similar to findings by Shoup et al. (2007). The last growth increment and initial length had been back-calculated from measurements taken along the posterior radius of basal sections of pectoral spines using the direct-proportion method. Recently, Michaletz et al. (2009) found that this procedure provided an initial length–last growth increment relationship that was similar to the actual relationship for captive channel catfish. The predicted growth increments for channel catfish with initial total lengths ranging from 200 to 600 mm at 25-mm intervals were used to estimate the 25th, 50th, and 75th percentiles for growth incremements (INC) for each 25-mm length-group among these 56 populations using PROC UNIVARIATE (SAS Institute 2005). Then linear regression was used to develop an equation between initial lengths (ITLs) and INCs for each percentile (i.e., separate equations for 25th, 50th, and 75th percentiles) using the 17 data points. The three regression equations (Figure 1) generated the predicted 25th, 50th, and 75th percentile INC for each ITL,

$$INC_{25th} = 90.16 - 0.16(ITL)$$

$$INC_{50th} = 131.80 - 0.23(ITL),$$

$$INC_{75th} = 180.84–0.30(ITL),$$

where INC_{25th}, INC_{50th}, and INC_{75th} are the predicted growth increments for the 25th, 50th, and 75th percentiles, respectively, and ITL is the initial total length in millimeters. All three equations had $r^2 > 0.99$ and $P < 0.0001$. The English equivalents of these equations are

$$INC_{25th} = 3.55–0.16(ITL),$$

$$INC_{50th} = 5.19–0.23(ITL),$$

$$INC_{75th} = 7.12–0.30(ITL),$$

where INC and ITL are in inches. These equations had r^2 and P-values similar to metric equations.

Development of the growth increment indices was restricted to fish with ITLs between 200 and 510 mm, excluding fish that had been stocked the previous fall. Recently stocked fish were identified by their age and excluded because their last INC occurred in rearing ponds. Fish with ITLs less than 200 mm were excluded because they were almost exclusively recently stocked, and fish with ITLs larger than 510 mm grew slowly, making it difficult to separate fast-growing from slow-growing fish because the three regression lines converged at ITLs larger than 510 mm (Figure 1) and predicted growth increments were negative for fish with ITLs larger than the 525-mm group.

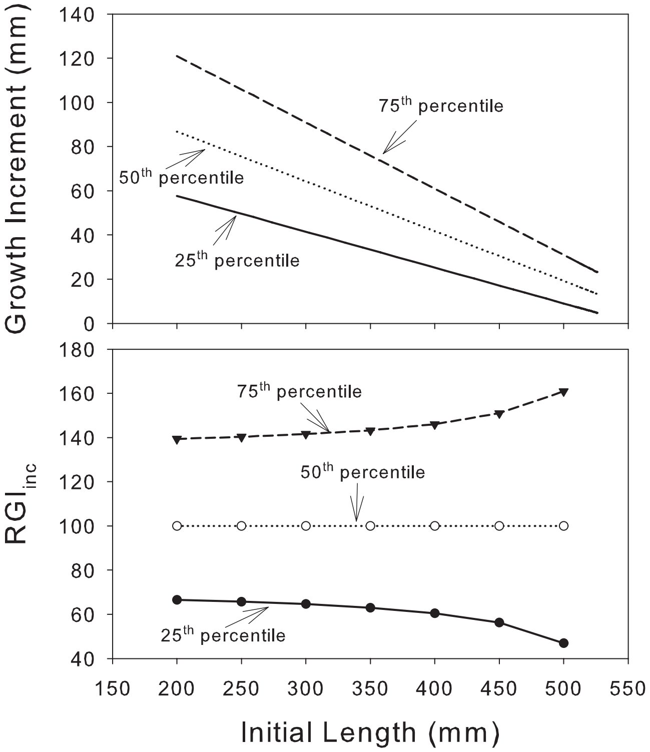

FIGURE 1. Regression lines relating growth increments to initial total lengths of channel catfish for the 25th, 50th, and 75th percentiles based on 56 channel catfish populations in small lakes in Missouri (top graph) and values of the relative growth increment index (RGI_{inc}) for fish growing at the 25th, 50th, and 75th percentiles (bottom graph). See the text for the regression equations for the top graph.

Two indices were calculated using the ITL–INC regression equations. The first index, the relative growth increment index (RGI_{inc}), was a modification of the relative growth index (RGI) developed by Quist et al. (2003). Quist et al. (2003) compared observed mean length at age (L_t) of walleyes *Sander vitreus* in Kansas reservoirs with standard lengths at age (L_s) computed from a pooled von Bertalanffy growth model, where RGI = $(L_t/L_s) \times 100$. The standard model was derived from multiple populations throughout North America. Jackson et al. (2008) developed RGIs for several additional species, including channel catfish. However, comparing mean length at age for channel catfish is not appropriate for stocked populations in Missouri because stocked fingerlings vary in size and age, making these comparisons problematic. Also, growth rates of fingerlings in hatchery rearing ponds are considerably faster than similar-age fish in more natural settings (Michaletz et al. 2009), which makes comparisons with nonstocked populations inappropriate. Instead, the 50th percentile ITL–INC equation was used to predict the standard INC (INC_s) for each ITL. Thus, $RGI_{inc} = (INC_o/INC_s) \times 100$, where INC_o is the observed INC for an individual channel catfish. The RGI_{inc} can range from 0 to ∞ and values less than 100 indicate below-average growth and values above 100 indicate above-average growth.

In order to calculate the second growth increment index, the incremental growth index (IGI), the estimate of INC_o for an individual channel catfish was compared with the INC values predicted from the three regression equations (25th, 50th, and 75th percentile equations) for the fish's ITL. The INC_o for each fish was assigned to one of four categories: <25%, 25–49%, 50–74%, or ≥75% (Figure 2). After the INC_o for all of the fish in the sample were categorized, the total number of fish in each category and in the entire sample were summed. The number of fish in each category was multiplied by the multiplier corresponding to that category (Figure 2) and these products were summed over all categories. The product sum was divided by the total sample size to compute the IGI. The IGI ranges from –2 to 2, with negative values indicating below-average growth and positive values indicating above-average growth.

If the previous calculations of RGIinc and IGI were derived from a fixed number of fish per length-group and not a random sample, their values may be biased if relative growth varies with fish length. For example, growth increments for larger fish may be above the 75th percentile while those of smaller fish may be below the 25th percentile. These differences in growth could lead to biases in the index values because the size distribution of fish in the entire population sample will probably

	Growth increment percentiles				
	< 25	**25-49**	**50-74**	**≥ 75**	
Number	23	17	4	2	**Total** = 46
Multiplier	-2	-1	1	2	
Product	-46	-17	4	4	**Product sum** = -55
				Index = -55/46 = **-1.2**	

FIGURE 2. Incremental growth index worksheet showing example data. See text for an explanation on the use of this worksheet.

be different than the size distribution of fish used to calculate the indices. To avoid this bias, index values could be calculated for each length-group and then a weighted mean could be calculated for the entire population sample by using the total number of fish per length-group in the entire sample as the weighting factors.

Application of the Indices

Methods

The growth increment indices were calculated for channel catfish populations in seven lakes where stocking rates were changed since the study by Michaletz (2009). These lakes were chosen because most represented extremes in growth rates of channel catfish and stocking rates had been substantially changed. Stocking rates were changed because either channel catfish populations exhibited poor growth and size structure, in which case stocking rates were reduced, or the populations exhibited fast growth and low abundance, in which case stocking rates were increased. Changes in stocking rates were determined by the fisheries managers based on their assessment of the magnitude of change in stocking rates that was needed to improve either growth and size structure or abundance of channel catfish. The study lakes ranged from slightly eutrophic to hypereutrophic and were all located in the northern half of Missouri (Table 1). All lakes had been previously sampled in May or June of 2001, 2003, and 2005 (Michaletz 2009). These lakes were sampled again in May or June of 2008 after the new stocking rates had been applied for 3 years. Channel catfish were sampled with cheese-baited tandem hoop net series fished for 3 days, as described by Michaletz and Sullivan (2002) and Michaletz (2009). Four tandem hoop net series were used in Cameron 1, Jo Shelby, and Ray County lakes; six series in Brookfield City and Hamilton City lakes; and eight series in Little Dixie and Marceline lakes. All captured channel catfish were counted and measured (total length) and pectoral spines were removed from five of these fish per 25-mm TL class to estimate age, ITL, and INC. Catch per unit effort (CPUE) was computed as the number of channel catfish caught per 3-d tandem series. To compare CPUE among years within a lake, analysis of variance (ANOVA) was used on $\log_e(X + 1)$-transformed values. Transformation was necessary to normalize the data. For significant ANOVA ($P \leq 0.05$), pairwise comparisons of least-square means were conducted using Tukey-Kramer adjusted *P*-values. Proportional size distribution (PSD; Guy et al. 2007; formerly proportional stock density) was computed according to Anderson (1980) and Gabelhouse (1984), using 280 mm TL as stock size and 410 mm TL as quality size, and 95% confidence intervals for PSD values were computed using procedures by Gustafson (1988).

The $\mathrm{RGI}_{\mathrm{inc}}$ and IGI were calculated for each lake following the weighted-mean procedure described in the previous section for samples collected in 2003 and 2005 (Michaletz 2009) and 2008 (this study). In addition, a weighted-mean INC was calculated for each lake and year, and Pearson correlation analysis was used to relate the two indices and the weighted mean INC. Because plots revealed that some relationships were curvilinear, INC values were also loge-transformed to linearize relationships.

Results

Although CPUE tended to decrease in lakes with reduced stocking rates and increase in lakes with increased stocking rates, few of these differences were significant (Table 1). Accordingly, PSD, weighted mean INC, $\mathrm{RGI}_{\mathrm{inc}}$, and IGI values were mostly similar across years for a lake (Table 1). Despite eliminating stocking for 3 years in Brookfield City, Hamilton City, and Marceline lakes, channel catfish populations sampled in 2008 still exhibited poor size structure and growth. Some natural recruitment occurred in all three lakes, which may prolong efforts to improve growth and size structure. Increases in stocking rates in Jo Shelby, Little Dixie, and Ray County lakes did not reduce growth, and size structure was similar to years with lower stocking rates. The 2008 sample from Ray County Lake consisted of only fish stocked the previous fall (age 2) and age-3 fish. The CPUE for the channel catfish population in Cameron 1 was much lower in 2008 than in previous years, but improvements in size structure and growth were not evident.

The two indices reflected differences in the weighted-mean INC among lakes and years (Table 1). Both $\mathrm{RGI}_{\mathrm{inc}}$ ($r = 0.98$, $P < 0.0001$, $N = 21$, Figure 3) and IGI ($r = 0.89$, $P < 0.0001$, $N = 21$) were highly correlated with mean INC. The relationship between IGI and INC was slightly curvilinear, and $\log_e$-transforming INC improved the fit ($r = 0.96$, $P < 0.0001$, $N = 21$; Figure 3). Both indices reflected differences in low, moderate, and fast growth (Table 1; Figure 3). Values for the two indices were also highly correlated ($r = 0.95$, $P < 0.0001$, $N = 21$).

Table 1. Total phosphorus concentration (TP), previous (Prev.) and current (Curr.) stocking rates (number of fingerlings/ha), catch per unit effort (CPUE, number of channel catfish per 3-d tandem hoop-net series), proportional size distribution (PSD, 695% confidence intervals), weighted mean growth increments (mm), incremental growth index (IGI) values, and relative growth increment index (RGI_{inc}) values for channel catfish populations in the study lakes (surface area in hectares, in parentheses) for samples collected in the spring of 2003, 2005, and 2008. For CPUE, values with no letters in common among years within a lake are significantly different ($P \leq 0.05$) for $\log_e(X + 1)$-transformed values. Water quality data were from Michaletz (2009). Previous stocking rates were used from fall 1998 to fall 2004, and current stocking rates were used from fall 2005 to fall 2007.

	TP	Stocking rate		CPUE			PSD			Increment			IGI			RGI_{inc}		
Lake	(µg/L)	Prev.	Curr.	2003	2005	2008	2003	2005	2008	2003	2005	2008	2003	2005	2008	2003	2005	2008
Brookfield (41)	41	74	0	348x	331xy	143y	5±1	2±1	4±2	23	28	24	–1.95	–1.93	–1.95	32.4	39.2	38.4
Cameron 1 (10)	10	74	37	90x	122x	13y	8±3	10±3	17±14	27	28	37	–1.86	–1.90	–1.74	42.1	44.0	55.9
Hamilton City (34)	34	74	0	352x	307x	104x	4±1	6±1	11±3	26	19	27	–1.92	–1.96	–1.89	38.2	29.6	46.4
Jo Shelby (12)	12	12	49	62x	2y	35xy	79±6	43^{ab}	56±9	70	55^{b}	88	1.29	–0.20^{b}	1.50	151.4	103.3^{b}	155.9
Little Dixie (83)	83	12	37	13x	18x	23x	65±11	77±8	71±8	51	43	56	0.11	0.07	0.23	105.3	109.5	119.4
Marceline (71)	71	74	0	345x	192x	189x	16±2	21±2	26±2	26	22	23	–1.88	–1.89	–1.81	49.5	40.2	47.2
Ray County (10)	10	12	25	33x	4x	8x	74±10	50±34	57±23	142	178	183	1.88	2.00	2.00	262.7	292.6	259.3

[a] Insufficient sample size to calculate confidence intervals.

[b] Computed from only three fish.

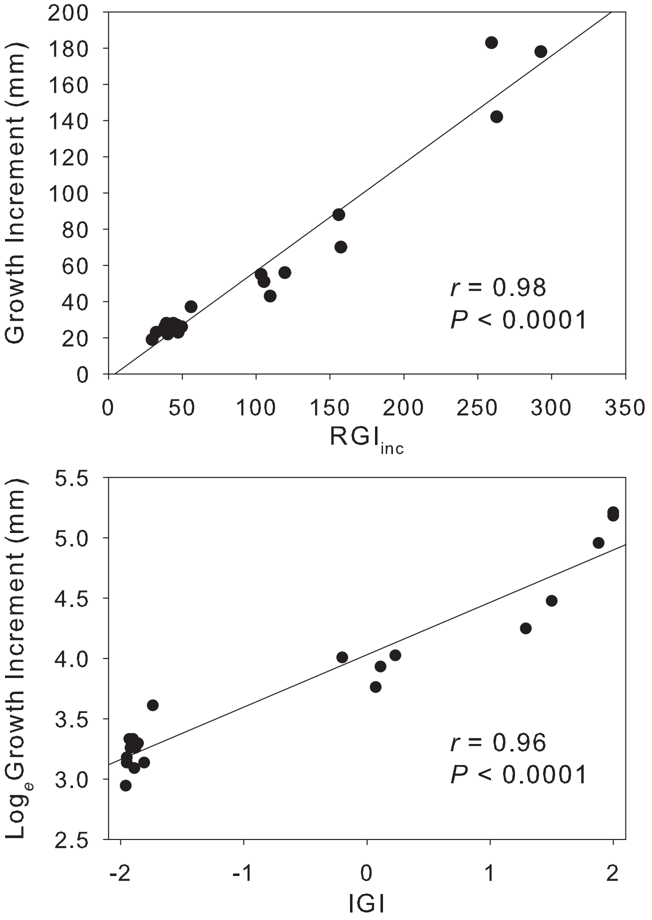

FIGURE 3. Linear relationships between the relative growth increment index (RGI_{inc}) and weighted-mean growth increments (top graph) and between the incremental growth index (IGI) and $\log_e$-transformed weighted-mean growth increments (bottom graph).

Discussion

Both indices reflected differences in mean growth increments among channel catfish populations and provided a measure of how well channel catfish grew relative to other populations in Missouri. Values less than 100 for RGI_{inc} and negative values for IGI indicated that channel catfish were growing slower than average, whereas values greater than 100 for RGI_{inc} and positive values for IGI indicated faster than average growth. Both indices could be useful in tracking relative growth over time in a population. Each index has advantages and disadvantages. The RGI_{inc} was more highly correlated with mean INC than was IGI and is simpler to calculate. However, with the exception of the 50th percentile upon which the index is calculated, RGI_{inc} values for fish growing at the same percentile changes across the range of ITL (Figure 1). For example, a fish with an ITL of 200 mm with an INC at the 25th percentile would have an RGI_{inc} of 66.6, whereas a fish with an ITL of 500 mm with an INC at the 25th percentile would have an RGI_{inc} of 46.9. Similarly, a 200-mm-ITL fish with an INC at the 75th percentile would have an RGI_{inc} of 139.4, whereas a fish with an ITL of 500 mm with an INC at the 75th percentile would have an RGI_{inc} of 160.9. Thus, RGI_{inc} did not consistently categorize fish relative to the standard percentiles across the range of ITL. This occurs because the range of potential INC narrows with increasing ITL. Another disadvantage of RGI_{inc} is that fish growing slower than the standard only had a range of values less than 100 down to 0, whereas fish growing faster than the standard had a range from >100 to ∞. Values for

RGI_{inc} approached 300 for Ray County Lake for example. In contrast, IGI has a restricted and balanced range for fish growing slower and faster than average, ranging from –2 to 2, and it consistently categorizes fish in relation to growth increment percentiles. Managers may be able to more readily identify with negative and positive values associated with below-average and above-average growth, respectively, than the potentially large range of values, especially for fast-growing fish, derived from RGI_{inc}.

Either index can be used to determine if stocking rates should be reduced, remain the same, or possibly increased. Strong negative values (values close to –2) for IGI or values much less than 100 for RGI_{inc} indicate that channel catfish are growing slowly and are probably overabundant. In these cases, stocking rates should be decreased with the degree of reduction, depending on the magnitude of the slow growth. Conversely, if the IGI is strongly positive (values close to 2) or RGI_{inc} values greatly exceed 100, channel catfish are growing well and there is an opportunity to increase the stocking rate, if more channel catfish are desired. The appropriate change in stocking rate in relation to the observed index values remains unknown and will likely be different for each situation. Managers will have to determine the appropriate changes through trial and error. If a change in stocking rate is made, the population can be sampled again in a few years and the index value compared with the previous one. Further adjustments in the stocking rate may be needed if the growth rate is not responding appropriately. This fine-tuning may take some time before desirable growth rates or densities occur. Also, objectives for channel catfish populations may vary among lakes, and the indices simply provide information that will assist biologists in making the appropriate management decisions to meet those objectives.

The application of the indices to the seven study lakes revealed that growth rates did not respond to the changes in stocking rates. The indices also indicated little change, reflecting the similarity of growth increments among years within a lake. These findings indicate that the new stocking rates may have to be applied several more years in order to measure changes in growth rates and in the indices. The length of time necessary for growth rates to improve will probably vary among lakes due to differences in angler harvest, natural mortality, food supply, and other factors. Low mortality coupled with some natural recruitment may prolong the recovery of slow-growing populations. For populations with fast growth rates, increases in stocking rates should be moderate because if overstocking occurs, it may take some time to reduce densities enough to improve growth. Obviously, many factors influence growth rates of channel catfish in addition to density. For some populations, growth rates may never be satisfactory, even at very low stocking rates, due to low lake productivity, poor habitat, inadequate prey, or other factors (Cole et al. 1991; Mosher 1999; Durham et al. 2005; Shephard and Jackson 2006; Michaletz 2009). The indices could be used to identify types of lakes that have little potential to support adequate growth rates of channel catfish. For these cases, stocking should possibly be discontinued if a population with adequate size structure cannot be developed.

Several factors could potentially bias estimates of relative growth. Sampling methods are size-selective and do not capture all sizes of fish in proportion to their abundance (Bonar et al. 2009). Because different-sized fish grow at different rates, sampling biases could affect estimates of relative growth. However, tandem hoop netting used to sample channel catfish in this study appears to be relatively unbiased for sampling fish larger than 250 mm TL (Michaletz and Sullivan 2002). Because only fish with ITLs between 200 and 510 mm TL were used to compute relative growth, biases in growth estimates were probably negligible. Selective harvest of fast-growing fish by anglers could also have biased growth estimates. Although this possibility cannot be entirely discounted, it is unlikely. Exploitation of channel catfish by anglers in northern Missouri lakes is frequently low (Michaletz et al. 2008). For example, 3-year cumulative exploitation of stocked channel catfish was only about 33% in Brookfield City Lake, and other northern Missouri lakes had exploitation rates less than 20% (Michaletz et al. 2008). Thus, estimates of growth rates were probably not significantly biased by the removal of faster-growing fish by anglers. Growth estimates could be biased if faster-growing fish suffered higher natural mortality than slower-growing fish. However, that is unlikely given that faster-growing fish typically experience lower natural mortality than slower-growing ones because they can forage on a wider array of prey (Michaletz 2006b) and are less vulnerable to predation (Marzolf 1957; Krummrich and Heidinger 1973; Spinelli et al. 1985).

The two indices were developed based on growth rates in small lakes in Missouri, but these indices could be easily modified for different growth rate patterns in other geographic areas. While some relative growth standards have been developed from populations across large geographic areas (Hubert 1999; Quist et al. 2003; Jackson et al. 2008), our more localized analysis is more useful to managers in Missouri. Our indices provide realistic growth standards for populations in Missouri, whereas using standards derived from a much broader area may not provide useful growth standards due to geographic differences in growth potential. However, the standards developed for Missouri may be applicable to other Midwestern states. For example, ranges of growth increments for fish of a given initial length were similar between Missouri and Illinois lakes (Shoup et al. 2007; Michaletz 2009).

In summary, the proposed indices should be useful in assessing stocking rates for individual lakes. Many factors influence channel catfish populations and individual growth rates reflect the combined effects of these factors. By comparing growth increments of fish with the same initial length to a statewide standard, problems related to comparing mean length at age in stocked populations can be avoided. Managers can use the indices to track changes in growth rates with changes in stocking rates and other management strategies. While not developed here, bootstrapping or other resampling procedures (Manly 1997) can be used to estimate confidence intervals for the indices, which can facilitate comparisons of the indices among years or lakes. In this case, the values for the indices were very similar across years within a lake, making it unlikely that they varied significantly.

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