North American Journal of Fisheries Management 29:614–625, 2009

DOI: 10.1577/M08-055.1

[Article]

Evaluation of Largemouth Bass Length Limits and Catch-and-Release Regulations, with Emphasis on the Incorporation of Biologists' Perceptions of Largemouth Bass Length Frequency Distributions

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Abstract.—A survey of fisheries biologists was used to assess changes in size structure of populations of largemouth bass *Micropterus salmoides* in relation to additional harvest regulations and to associate biologists' perceptions with various measures of length frequency changes. Biologists were presented with largemouth bass population data from regulated and control fisheries and then were asked to judge whether they perceived that the population size structure had improved over time. A blind survey approach was used (biologists did not know which populations received the additional regulations or which were control fisheries). We developed statistical models that include lake, regulation type, and biologist effects and compared them with traditional statistical analyses of regulation effectiveness. Based on perceptions of fisheries biologists about length frequency changes, 12-in maximum length limits and catch-and-release regulations were about four times more likely to improve the size structure than just reliance on standard bag limits (the regulation on control fisheries). Improvement in size structure substantially beyond a statistically significant change was often needed before a regulation was considered successful by fisheries biologists. Individuals differed in their propensity to see changes as improvements. The advantages and caveats of using biologists' perceptions as a component of regulation analyses were discussed. A similar approach using angler questionnaires may yield informative data on what constitutes an improved fishery.

Length-based regulations are a popular tool for managing fisheries (Radomski et al. 2001). Length-based harvest regulations are typically enacted to improve a fishery by increasing the number and frequency of larger fish within a population and to increase angler catch rates (Noble and Jones 1999). Studies evaluating the effectiveness of various length-based regulations in altering or improving the size of various fish species are still common (e.g., Wilde 1997; Fayram et al. 2001; Paukert et al. 2007).

Specific attention has been given to altering the size structures of populations of largemouth bass *Micropterus salmoides* (Wilde 1997). The responses of largemouth bass populations to length and catch-and-release regulations have been mixed. Wilde (1997) reported that protected slot limits were generally effective in increasing largemouth bass size structure, while minimum length limits did not generally improve size structure but did result in increased angler catch rates. Regulation study designs are often chronically limited in their power to detect fish population change in light of environmental variability (Allen and Pine 2000; Radomski et al. 2001). Often, regulation studies only evaluate a few lakes during a very limited time period (i.e., $\leq$2 years for pretreatment and treatment periods each) and rarely incorporate control lakes. Fish population responses to regulations may also be dependent on regional-, lake-, or fishery-specific characteristics and on angler attitudes. For example, angler noncompliance may influence regulation effectiveness (Pierce and Tomcko 1998; Sullivan 2002; Page and Radomski 2006). The adoption of greater replication (i.e., more experimental lakes), control lakes, and longer preregulated and regulated evaluation periods has been advocated for regulation studies in order to control experimental variance, increase power, and increase the potential applicability of study results to other fisheries (Wilde 1997; Allen and Pine 2000; Isermann 2007).

In addition to these limitations, most length-based

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Received March 11, 2008; accepted October 20, 2008
Published online May 11, 2009

and catch-and-release regulation evaluations fail to fully address how fish population responses following the implementation of regulation relate to fisheries biologists' perceptions. Analyses are frequently limited to comparisons of various population or fishery metrics (e.g., size structure indices, catch rates, length frequency distributions, and testing for a regulation [treatment] effect). However, fisheries biologists must not only consider the effectiveness of regulation within a biological context but also within a political and social context as well (Jakus et al. 1996; Malvestuto and Hudgins 1996). Fisheries managers must often make regulation decisions with little data. Conclusions about harvest regulations have often been made on the weight of the evidence from previous case histories. Therefore, fisheries biologists likely possess unique perspectives on the effectiveness of regulations that have not been traditionally considered as part of the regulation analyses.

For this study, we sought to evaluate harvest regulations (catch and release and 12-in maximum length limit) in improving the size structure of Minnesota largemouth bass populations. Largemouth bass populations were evaluated over multiple years encompassing both preregulated and regulated periods, along with a set of control lakes that were regulated with statewide harvest regulations. The objective of this study was to conduct a simple evaluation of the perceptions of fisheries biologists, who visually inspected length frequency distributions and size structure indices, on the apparent success or failure of these regulations in altering largemouth bass size structure.

Methods

Fisheries data collection and analysis.—Nineteen largemouth bass fisheries (12 fisheries having additional regulations and seven control fisheries) were selected for this study (Table 1). Largemouth bass lakes used in this study were a subset of fisheries from a multispecies, statewide investigational project designed to determine the value of length-based harvest regulations in Minnesota. The fisheries within the project were not chosen at random. From 1992–1993, candidate lakes for the project were selected using available biological data about sport fish species (e.g., length frequency data, catch-per-unit-effort data) and recommendations provided by fisheries managers and the public. Potential regulations were assigned to largemouth bass fisheries within candidate lakes based on fish population and fisheries characteristics (e.g., growth rates, abundance, and angler catch rates). Final selections of lakes and associated regulations were determined with consultations between fisheries managers and the public during 1995 and 1996. Public

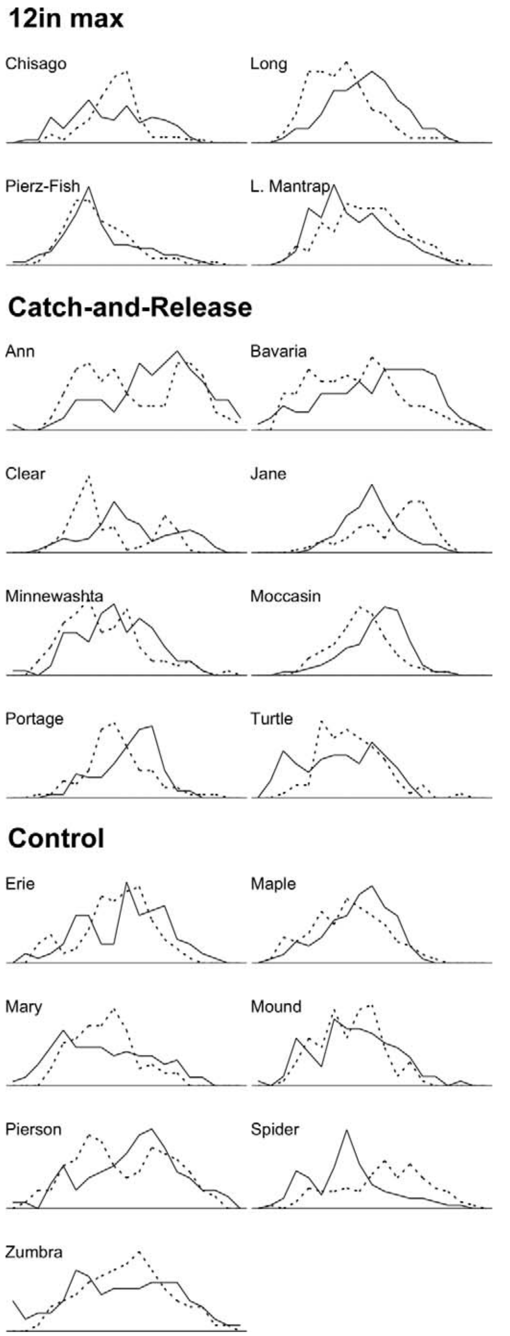


FIGURE 1.—Relative length frequency distributions for 19 largemouth bass populations in Minnesota from time period 1 (dotted line) and 2 (solid line) for control, 12-in maximum length limit, and catch-and-release fisheries. The scale along the horizontal axis is from 3 to 21 in, and the scale along the vertical axis for each plot is based on the maximum proportion in a length bin for the population. For regulated fisheries, time period 1 is preregulation years, and time period 2 is regulated years.

TABLE 1.—Attributes, fish survey statistics, and regulations for 19 Minnesota largemouth bass fisheries for which fisheries professionals were surveyed as to their perceptions of improvement, winter 2004–2005 (numbers in parentheses = 95% confidence intervals, max = maximum length limit, CR = catch and release, slot = protected slot limit, PSD = proportional stock density, RSD = relative stock density, N = number of fish measured, K–S P = Kolmogorov–Smirnov test probability, % yes = percentage of respondents that said the size structure improved from time period 1 to time period 2, Regulation after investigation = fisheries management decision after the length regulations investigation project was completed).

				Time period 1 (preregulation)				
Lake Fishery	Lake size (ha)	Type	Regulation	PSD	RSD	Mean length	N	Number of surveys
Chisago	376	Regulated	12-in max	21 (17–25)	7 (4–10)	11.1 (10.9–11.3)	321	3
Long	144	Regulated	12-in max	25 (22–28)	5 (4–6)	9.6 (9.4–9.8)	1,104	5
Pierz-Fish	75	Regulated	12-in max	24 (18–30)	5 (2–8)	9.6 (9.3–9.9)	195	2
Little Mantrap	159	Regulated	12–18-in slot	54 (48–60)	17 (12–22)	11.6 (11.3–11.9)	428	3
Ann	49	Regulated	CR	58 (54–62)	43 (39–47)	12.7 (12.3–13.1)	415	3
Bavaria	81	Regulated	CR	58 (54–62)	21 (17–25)	10.8 (10.1–11.1)	497	3
Clear	247	Regulated	CR	31 (22–40)	24 (16–23)	10.6 (10.0–11.2)	106	2
Jane	61	Regulated	CR	80 (75–85)	51 (45–57)	13.9 (13.5–14.3)	240	3
Minnewashta	299	Regulated	CR	39 (33–45)	12 (8–16)	10.1 (9.7–10.5)	268	3
Moccasin	105	Regulated	CR	46 (42–50)	8 (0–17)	11.2 (11.0–11.4)	811	4
Portage	114	Regulated	CR	42 (38–46)	8 (0–17)	11.1 (10.9–11.3)	555	3
Turtle	180	Regulated	CR	32 (25–39)	5 (1–9)	10.5 (10.1–10.9)	146	3
Erie	79	Control		61 (57–65)	13 (10–16)	11.3 (11.0–11.6)	502	3
Maple	351	Control		39 (31–47)	7 (3–11)	10.1 (9.7–10.5)	169	2
Mary	79	Control		33 (25–41)	7 (2–12)	10.2 (10.0–10.4)	438	2
Mound	115	Control		40 (34–53)	8 (4–12)	10.3 (10.0–10.6)	219	2
Pierson	138	Control		56 (52–60)	32 (29–35)	11.7 (11.5–11.9)	1,547	5
Spider	240	Control		76 (71–81)	41 (35–47)	12.9 (12.4–13.4)	234	3
Zumbra	89	Control		64 (62–66)	26 (24–28)	12.0 (11.8–12.2)	1,612	5

support for candidate lakes and regulations was required for ultimate selection of a lake into the project. Regulations were implemented on study lakes in the springs of 1995–1997 (Table 1).

Lakes were sampled using standard electrofishing techniques (MDNR 1993). Sampling was conducted intermittently during years prior to and during regulation implementation. Fisheries management staff in areas participating in the project conducted the field surveys and provided length frequency distributions. For each fishery, relative length frequency distributions were calculated for preregulation and regulation time periods using all surveys from each time period (control fishery surveys were also separated into two time periods, representing the same time frames as those of regulation fisheries; Figure 1). Relative length frequency distributions were calculated by summing all fish captured within the time period by length bin divided by the total fish captured in the time period. Surveys conducted during the initial year of a regulation were not included as the initial regulated year was considered a transition year. Relative length frequencies give each fish collected equal weight, uncorrected for the effort to capture it, and such representations of size structure may not be the best metric. For example, a biologist trying to evaluate whether the number of large fish increased would have to mentally factor in the fish sample sizes, the number of surveys in each time period, and a best guess as to whether the sampling effort was equal in each survey and time period. While the use of relative length frequency distributions may have increased the difficulty in judging changes in the size distribution between the two time periods for some fisheries, relative length frequency distributions may be more robust to changes in survey effort and catchability, which was a common issue with the fish surveys used (McInerny and Cross 2000).

The length data were analyzed using various statistics. A two-sample, one-tailed Kolmogorov–Smirnov test was used to examine the differences between length frequency distributions. The size structure of the largemouth fisheries for preregulation and regulation years was also characterized with mean size and proportional and relative stock density (PSD and RSD, respectively; Anderson and Weithman 1978). Confidence intervals for PSDs were approximated as presented by Gustafson (1988). A weighted mean difference between relative length frequency distributions from time period 2 (regulation) and 1 (preregulation) was determined for each fishery using the lower class limits of length frequency bins from 3 to 21 in as weighting factors. The weighted mean difference (Δ) was calculated as

TABLE 1.—Extended.

Lake Fishery	Time period 2 (regulation) PSD	RSD	Mean length	N	Number of surveys	K–S P	% yes	Regulation after investigation
Chisago	52 (47–57)	19 (15–23)	10.8 (10.4–11.2)	303	3	0.0063	91	12-in max remained
Long	56 (52–60)	16 (13–19)	11.6 (11.2–12.0)	556	3	1	95	Changed to 12-in max with one fish > 20-in
Pierz-Fish	32 (27–37)	12 (8–16)	10.0 (9.7–10.3)	314	3	0.8480	46	Changed to 12-in max with one fish > 20-in
Little Mantrap	43 (38–48)	14 (9–19)	10.5 (10.2–10.8)	412	3	0.0261	1	12–18-in slot remained
Ann	81 (79–83)	55 (52–58)	14.3 (14.1–14.5)	1,158	6	0.9902	88	CR remained
Bavaria	70 (68–72)	41 (39–43)	12.6 (12.4–12.8)	1,941	6	0.9160	96	Reverted to statewide regulation
Clear	60 (55–65)	31 (27–35)	12.3 (12.0–12.6)	392	6	0.9902	83	CR remained
Jane	61 (57–65)	13 (10–16)	12.0 (11.8–12.2)	423	4	0	1	CR remained
Minnewashta	50 (43–57)	15 (10–20)	11.1 (10.6–11.6)	172	3	0.9612	58	CR remained
Moccasin	75 (72–77)	13 (7–19)	12.3 (12.2–12.5)	1,064	5	0.9900	88	CR remained
Portage	70 (68–73)	13 (7–19)	12.2 (12.1–12.4)	926	5	0.9616	87	CR remained
Turtle	47 (42–52)	5 (3–7)	9.5 (9.2–9.8)	403	4	0.0075	13	CR remained
Erie	69 (65–73)	40 (36–44)	11.9 (11.6–12.2)	474	6	0.6304	64	
Maple	52 (43–61)	5 (1–9)	10.9 (10.5–11.3)	114	2	0.9565	42	
Mary	52 (46–58)	22 (17–27)	10.1 (9.8–10.4)	671	5	0.0888	80	
Mound	48 (43–53)	13 (9–17)	10.5 (10.3–10.8)	360	3	0.6289	26	
Pierson	75 (72–78)	48 (45–51)	12.5 (12.3–12.7)	1,268	4	0.9887	81	
Spider	32 (25–39)	11 (6–16)	10.0 (9.5–10.5)	174	2	0	1	
Zumbra	62 (60–64)	35 (33–37)	11.5 (11.3–11.7)	1,355	4	0.2154	24	

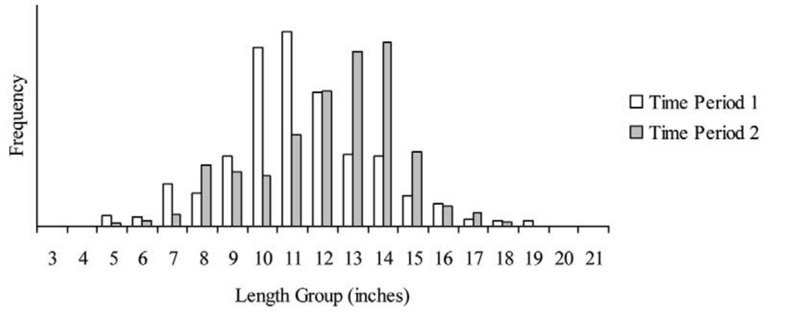
$$\Delta = \sum_{i=3}^{21} 100 b_i (p_{2,i} - p_{1,i}) / \sum_{i=3}^{21} b_i,$$

where b_i is the ith length bin, and $p_{t,i}$ is the proportion observed in the ith length bin in time period t. With this statistic, the differences of the relative catch of large fish between the two time periods are more important than the differences in relative catch of small fish.

Fisheries biologist survey.—We conducted a survey in which fisheries biologists (either supervisors or nonsupervisors) were presented with largemouth bass population data from regulated and control fisheries and then asked to judge whether they perceived that the population size structure had improved during regulated years compared with preregulated years. The manager category included staff of supervisory or higher rank in the Minnesota Department of Natural Resources (MDNR), who thus had greater internal authority and possibly more experience than specialists. We refer to the two management-classes collectively as fisheries biologists. A questionnaire template was developed, and the 19 fisheries' statistics were placed within the template. Survey questions are shown in Figure 2, along with an example of the fisheries statistics provided.

The questionnaire was sent to all MDNR fisheries professionals from 28 field area stations across the four MDNR administrative regions of the state. A "blind" survey approach was used in that biologists did not know which populations were regulated or controlled. The main question asked for all fisheries and to each person was, "Would you say that the size structure of this fish population improved from time period 1 to time period 2?" To avoid a potential source of bias, the order in which the 19 fisheries were presented was randomized for each person. We assumed that questionnaires not returned were missing completely at random (i.e., the data were missing with no pattern related to perception of size structure changes). To minimize the impact of nonresponse bias, the questionnaire was concise and confidentiality was kept.

We wished to evaluate whether there was a difference in the categorization of regulated populations versus control populations. For example, if controlled populations are categorized as "improved" just as often as regulated populations, then this may argue that differences in population structure observed between preregulated and regulated years may be related to factors other than the regulation. More importantly, we wished to determine if the regulations improved Minnesota largemouth bass fisheries as judged by fisheries professionals. It was assumed that as more fisheries professionals responded affirmative-



	PSD	RSD(15)	Mean Length (in)	Total Fish Measured	Years Sampled
Time Period 1	42 (38-46)	8 (0-17)	11.1 (10.9-11.3)	555	3
Time Period 2	70 (68-73)	13 (7-19)	12.2 (12.1-12.4)	926	5

Note: Numbers in parentheses represent 95% confidence intervals.

Would you say that the size structure of this fish population improved from time period 1 to time period 2? Yes___ No___

Please check the factor(s) that lead to your decision:
Length Frequency ___ Mean Length ___ Quality of Data ___
PSD ___ RSD(15) ___

FIGURE 2.—Part of the fisheries biologist survey questionnaire used in this study (PSD = proportional stock density; RSD = relative stock density).

ly, the likelihood increased that the fishery had actually improved in a meaningful way.

Statistical analysis of survey responses.—Responses to the question of whether the fishery improved were analyzed using a Bayesian framework (Carlin and Louis 2000). The benefits of a Bayesian approach for this analysis are that it allows a hierarchical data structure, a statistical model, and the ability to incorporate prior information while providing intuitive results. Hierarchical models, like traditional fixed-effects models, begin with the specification of sampling distribution for data determined by parameters, and the added structure of hierarchical models arises when the parameters themselves are thought of as sampled from probability distributions. The purpose of using hierarchical models here is to make probability statements about the distribution of parameters, given the data and assumptions about how the parameters are distributed. Eight hierarchical models were developed suitable for computation in WinBUGS, a freely available computer software package for the Bayesian analysis of complex statistical models using Markov chain Monte Carlo methods (Spiegelhalter et al. 2003). The first model (model 1) constructed was expressed in equation form as

$$Y_{i,j,k} \sim \text{binomial}(p_{i,j,k}, 1),$$
$$\text{Logit}(p_{i,j,k}) = \theta_{i,j} + \gamma_k,$$
$$\theta_{i,j} \sim N(\mu_j, \upsilon^2), \quad \text{and}$$
$$\gamma_k \sim N(0, \sigma^2),$$

where $Y_{i,j,k}$ is the binomial response for improvement for lake i under regulation type j as judged by biologist k, $p_{i,j,k}$ is the expected probability of an affirmative response, $\theta_{i,j}$ is a random effect for lake i and was assumed to be normally distributed with a mean μ_j that was dependent on the regulation type effect j (1 = control, 2 = 12-in maximum [one fishery had a 12–18-in protected slot limit, which was treated in this study as a 12-in maximum regulation], and 3 = catch and release) and variance υ^2, and γ_k is a random effect for individual biologist (assumed to be normally distributed with mean 0 and variance σ^2). The γ_k effect measures the "propensity" of any given biologist to see improvement, and it incorporates the variability among biologists in their professional judgments and also accounts for the correlation arising from the same biologist rating multiple lakes. The model is hierarchical in that the γ_k and $\theta_{i,j}$ parameters are drawn from priors that depend on unknown parameters (η_j, υ, and σ), which are, in turn, drawn from second-stage priors. Uninformative second-stage priors were given for υ and σ (uniform on the interval 0–10 on the logit scale). The variability of the random effect for lake, υ^2, was assumed to be universal in that natural variability in the dynamics of the fisheries and the environment was assumed to be similar across regulation types. The parameter η_1 was given an essentially uninformative uniform beta distribution (i.e., beta[1, 1]), while the priors for η_2 and η_3 were given informative beta distributions (i.e., beta[11, 30]) based on Wilde (1997), who reported that slot length limits resulted in increased largemouth bass PSD in 30 of 41 studies. We then calculated

$$\mu_j = \log_e[\eta_j/(1 - \eta_j)]$$

in order to appropriately inform sampling of $\theta_{i,j}$ on the logit scale. To ensure stability of the results, the Gibbs sampling algorithm was run for 10,000 updates after the first 1,000 were discarded for burn-in (this algorithm is a special case of the Metropolis–Hastings algorithm used here to generate a sequence of samples from the joint probability distributions of the random variables). Posterior medians and 95% credible intervals for parameters were determined. For some parameters estimated on the logit scale, odds ratios were computed as the inverse of the natural logarithm of the posterior medians.

The other seven models constructed included options of pooling of the two regulation types (12-in maximum and catch and release pooled as one type, control as the other) and the addition of effects for the biologist management-class (specialist or manager) and MDNR administrative region (1 = northwest part of state, 2 = northeast part of state, 3 = central part of state, and 4 = southwest part of state). To facilitate comparisons between models, all models used only the 73 of the 78 returned surveys that included the known management-class and MDNR administrative region of the biologist who completed the survey (number of responses = 73 biologists × 19 lakes = 1,387). The deviance information criterion (DIC), a generalization of Akaike's information criterion, was used to select the preferred model (Spiegelhalter et al. 2002). The values of DIC have no intrinsic meaning; however, smaller DIC values suggest better models based on the measure of fit and the effective number of parameters (i.e., model complexity). The WinBUGS code for the first model is given in Appendix 1. The posterior median of the lake effect θ was correlated with the Kolmogorov–Smirnov test probability examining the differences between length frequency distributions of the two time periods, the weighted mean difference between relative length frequency distributions, and the PSD difference from time periods 2 and 1.

TABLE 2.—Number of responses and the proportions of 73 Minnesota fisheries professionals (nonsupervisors, supervisors, and all biologists) that indicated which factors led to their decision as to whether the size structure of the largemouth bass population improved (yes) or not (no) between time periods 1 and 2 (PSD = proportional stock density; RSD = relative stock density).

Factor	Yes	No
Nonsupervisors		
Responses (*N*)	620	487
Length frequency	0.87	0.83
Mean length	0.48	0.59
PSD	0.71	0.53
RSD	0.71	0.59
Quality of the data	0.42	0.44
Supervisors		
Responses (*N*)	196	154
Length frequency	0.69	0.79
Mean length	0.46	0.55
PSD	0.68	0.42
RSD	0.72	0.59
Quality of the data	0.49	0.50
All biologists		
Responses (*N*)	816	641
Length frequency	0.83	0.82
Mean length	0.48	0.58
PSD	0.70	0.50
RSD	0.71	0.59
Quality of the data	0.44	0.46

Results

Most regulated and many control fisheries had proportionally larger fish in time period 2 or the regulation period compared with time period 1 or the preregulation period (Table 1). Eight of the twelve regulated fisheries had higher values for PSD, RSD, and mean length. Similarly, three of the seven control fisheries had higher values for these three statistics. In many cases, these statistics were significantly higher in time period 2 compared with time period 1. Appreciable positive differences in PSD and mean lengths of largemouth bass populations between preregulation and regulation years were observed in six of the eight fisheries where catch-and-release regulations were in effect.

For a number of lakes, observed shifts in relative length frequency distributions were consistent with expectations based on length limits (increased frequency of protected lengths) and, for a number of lakes, appeared to be dependent on the preregulation

TABLE 3.—Suite of candidate models used to understand the responses of Minnesota fisheries professionals to the question of whether a largemouth bass fishery improved, as ranked by deviance information criterion (DIC), and the posterior medians of selected parameters. Numbers in parentheses represent 95% credible intervals. All models included regulation type effects (control, 12-in maximum, catch and release; or control and regulation, where the 12-in maximum and catch-and-release regulations were pooled), some models included management-class effects (nonsupervisor or supervisor), and some included Minnesota Department of Natural Resources administrative region (1–4) effects. All models included effects for 19 lakes and 73 individual biologists (not shown here).

Model	Regulation type effect	Other effects	DIC
1	Control: −0.3816 (−2.301–1.428)		982.981
	12-in max: 0.9874 (0.354–1.695)		
	Catch and release: 1.009 (0.3706–1.693)		
2	Control: −0.4235 (−2.288–1.445)		983.083
	Regulation: 0.9761 (0.3564–1.649)		
3	Control: −0.386 (−2.24–1.467)	Management-class effect	983.189
	Regulation: 0.9781 (0.357–1.64)	Nonsupervisor: 0	
		Supervisor: −0.128 (−0.9014–0.6328)	
4	Control: −0.7413 (−2.695–1.171)	Region effect	983.200
	Regulation: 0.9079 (0.2928–1.58)	Region 1: 0	
		Region 2: 0.6573 (−0.232–1.537)	
		Region 3: 0.6575 (−0.2353–1.562)	
		Region 4: 0.7204 (−0.2715–1.658)	
5	Control: −0.7286 (−2.684–1.168)	Region effect	983.523
	12-in max: 0.9617 (0.3055–1.667)	Region 1: 0	
	Catch and release: 0.9651 (0.3281–1.627)	Region 2: 0.6364 (−0.2587–1.534)	
		Region 3: 0.649 (−0.2578–1.54)	
		Region 4: 0.6897 (−0.2601–1.677)	
6	Control: −0.3943 (−2.237–1.395)	Management-class effect	983.603
	12 in max: 0.9872 (0.3562–1.708)	Nonsupervisor: 0	
	Catch and release: 1.005 (0.3693–1.708)	Supervisor: −0.1278 (−0.9077–0.6649)	
7	Control: −0.7199 (−2.732–1.216)	Management-class × region effect	984.143
	12-in max: 0.9637 (0.3228–1.679)	Nonsupervisor region 1: 0	
	Catch and release: 0.9617 (0.3268–1.638)	Nonsupervisor region 2: 0.6337 (−0.4582–1.673)	
		Nonsupervisor region 3: 0.8055 (−0.3402–1.901)	
		Nonsupervisor region 4: 0.6794 (−0.5455–1.913)	
		Supervisor region 1: 0.1109 (−1.361–1.551)	
		Supervisor region 2: 0.9405 (−1.31–3.18)	
		Supervisor region 3: 0.1471 (−1.555–1.799)	
		Supervisor region 4: 0.7977 (−0.7486–2.329)	
8	Control: −0.7857 (−2.796–1.155)	Management-class × region effect	984.282
	Regulation: 0.8959 (0.2717–1.582)	Nonsupervisor region 1: 0	
		Nonsupervisor region 2: 0.6971 (−0.2827–1.711)	
		Nonsupervisor region 3: 0.8763 (−0.1173–1.92)	
		Nonsupervisor region 4: 0.7666 (−0.4049–1.958)	
		Supervisor region 1: 0.1772 (−1.212–1.591)	
		Supervisor region 2: 1.041 (−1.11–3.204)	
		Supervisor region 3: 0.1788 (−1.419–1.802)	
		Supervisor region 4: 0.8558 (−0.6115–2.361)	

population size structure (Figure 1). That is, lakes with fish populations that initially possessed proportionally few large individuals were more likely to benefit when the regulation was implemented. Relative length frequency distributions for Bavaria, Chisago, Long, Moccasin, and Portage lakes appeared to have a greater proportion of fish in the length-groups greater than 12 in for the regulated time period.

Seventy-eight biologists returned questionnaire packages out of the approximately 140 (~56%) surveys distributed to MDNR fisheries professionals. A large proportion of fisheries supervisors returned the questionnaire (19 of 28, or 68%), and the return rate across MDNR administrative regions was similar. Fifty-six percent of all responses reported that the size structure improved from time period 1 to time period 2. The most important factor in the decision-making process for determining whether a fishery improved was the relative length frequency distribution; over 80% of the biologists reported that visual inspection of these data led to their decision (Table 2). Interestingly, the quality of the data appeared to be a minor factor in their decision for both supervisors and nonsupervisors.

Responses of fisheries biologists to the question of whether a largemouth bass fishery improved were investigated using eight models. The preferred hierarchical model, based on lowest DIC (model 1 in Table 3), was the model with regulation effects (control, 12-in maximum, and catch and release), effects for lake in regulation type, and biologist effects. More complex

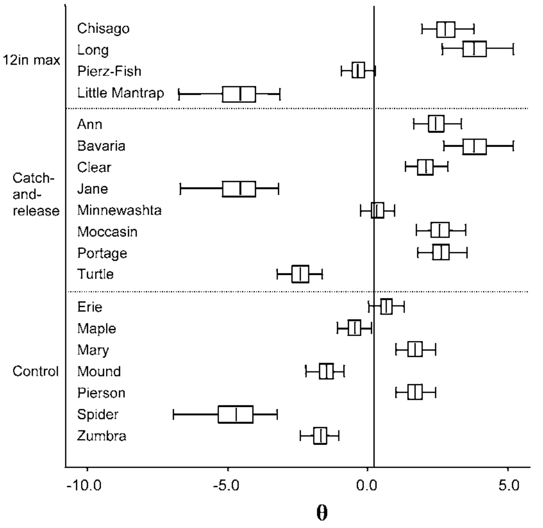


FIGURE 3.—Posterior distributions of the lake effect θ determined by the preferred hierarchical model (model 1 in Table 3). The box represents the interquartile range, the error bars represent the 95% credible intervals, the line within the box represents the median, and the horizontal line represents the overall mean. Box plots are grouped by regulation type, where "max" refers to maximum length limit.

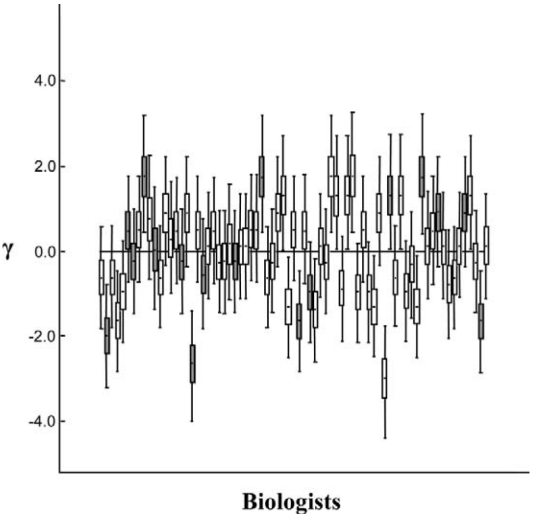


FIGURE 4.—Posterior distributions of the biologist effect γ determined by the preferred hierarchical model (model 1 in Table 3). The box represents the interquartile range, the error bars represent the 95% credible intervals, the line within the box represents the median, and the horizontal line represents the overall mean. Shaded box plots represent supervisors.

models that included effects for the biologist's management-class and MDNR administrative region were less parsimonious as they had higher DIC values. In addition, models that pooled regulation types did not improve goodness of fit.

Lakes with 12-in maximum length limits and catch-and-release regulations had higher posterior medians for the regulation type effect than for those for the control lakes (Table 3). Lakes with posterior medians greater than zero meant that biologists were more likely to judge the fisheries as improved. For the preferred model, the odds ratios for control, 12-in maximum length limit, and catch-and-release fisheries were 0.68, 2.68, and 2.74, respectively. Based on perceptions of fisheries biologists about length frequency changes, 12-in maximum length limits and catch-and-release regulations were about four times more likely to improve the size structure than just reliance on standard bag limits (the regulation on control fisheries). Posterior medians of the lake effect θ for regulated lakes were generally greater than those for control lakes (Figure 3). Posterior distributions of the biologist effect γ (determined by the preferred model) appeared not to differ by the biologist's management-class (Figure 4). Models that included management-class had overlapping 95% credible intervals for supervisors and nonsupervisors (Table 3). Some biologists had a propensity to be optimists (or generous) and see improvements in most fisheries, and some biologists were more pessimistic (or cautious) and did not. Models that included the MDNR administrative region suggested that, on average, biologists in region 1 (northwest part of the state) were more pessimistic than biologists from the other regions.

The lake effect θ was correlated with several easy-to-calculate, length-based statistics. Lake effect was weakly correlated with probability from the Kolmogorov–Smirnov test for a difference between the regulation and preregulation relative length frequency distributions ($r^2 = 0.44$; Figure 5). Two low probabilities from the Kolmogorov–Smirnov test, indicating a potential lack of improved size structures, had positive posterior medians for lake effect (Mary and Chisago lakes). Better predictors of lake effect were the weighted mean difference between relative length frequency distributions from time periods 2 and 1 ($r^2 = 0.76$; Figure 6) and PSD ($r^2 = 0.74$; Figure 7). Largemouth bass fisheries that were assessed by fisheries biologists as improved generally had positive weighted mean differences in relative length frequencies and PSD increases greater than 20. Interestingly, for lakes where fisheries biologists noted clear improvements in size structure (i.e., 95% credible intervals for lake effect θ were positive), the mean difference in PSD values between the lower 95% confidence limit in time period 2 and the upper 95% confidence limit in time period 1 was 16.1. This

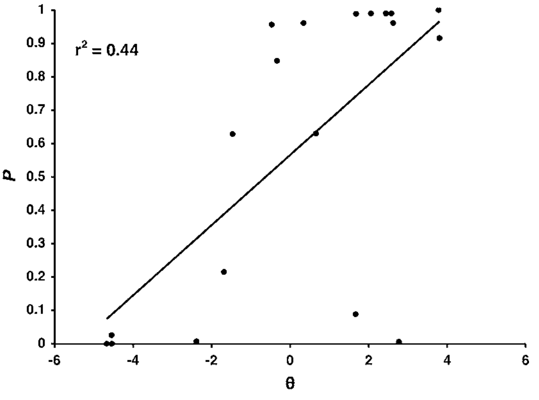


FIGURE 5.—Relationship between the probability *P* of obtaining a result that there was a difference concerning the regulation and preregulation largemouth bass length frequency distributions (using the Kolmogorov–Smirnov test probability) and the posterior median of the lake effect θ determined by the preferred hierarchical model (model 1 in Table 3).

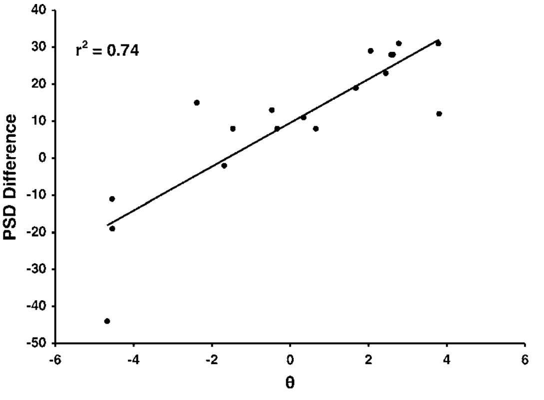


FIGURE 7.—Relationship between the largemouth bass proportional stock density (PSD) difference from time periods 2 and 1 and the posterior median of the lake effect θ determined by the preferred hierarchical model (model 1 in Table 3).

suggests that from the perspective of most fisheries biologists, improvement in size structure substantially beyond those that would produce a statistically significant change at the 95% confidence level in PSD are often needed before a regulation would be considered successful. Judgments about success may depend on the magnitude of the effect, whereas statistical significance also depends on sample sizes and the significance level.

Discussion

Harvest regulations can have appreciable consequences for the quality of fisheries. In a review of largemouth bass length limit studies, Wilde (1997) estimated that slot length limits were about three times more likely to improve the size structure of the population, as determined by increases in PSD values with length regulation, than just reliance on standard bag limits (the default control regulation). Our study, based on perceptions of fisheries biologists about length frequency changes, indicated that 12-in maximum length limits and catch-and-release regulations were about four times more likely to improve the size structure than just reliance on standard bag limits. Fisheries management agencies in North America continue to expand use of slot length limits to reduce dependence on bag limits (Paukert et al. 2007).

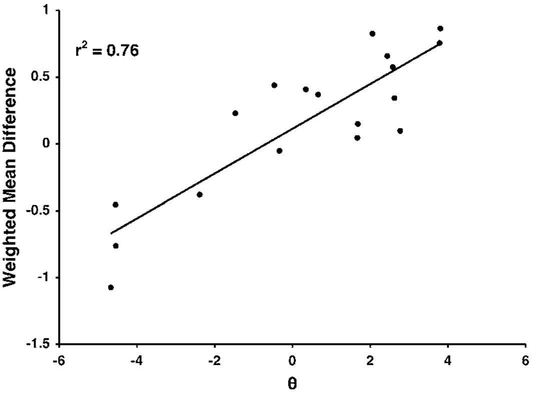


FIGURE 6.—Relationship between the weighted mean difference in largemouth bass relative length frequency distributions from time periods 2 and 1 and the posterior median of the lake effect θ determined by the preferred hierarchical model (model 1 in Table 3).

Individual propensities in perceiving success of regulations differed widely among biologists. Supervisors, who have greater decision-making authority, were slightly more pessimistic or cautious regarding the perceived success of harvest regulations, though individual propensities differed widely in each group. However, in some places, if a regulation has been shown to be ineffective but not detrimental to a fishery, then the regulation often remains. In part, this may be why fisheries biologists within our study required a difference in measures of size structure (e.g., PSD) well beyond what was statistically significant at the 95% confidence level before concluding that a regulation had resulted in a positive change in the largemouth bass size structure. In order to avoid conflicts with anglers, managers may resist adopting changes in regulations that contradict angler opinions unless the evidence for change in regulations exists. In addition, variation in perceptions of regulation success among biologists makes it hard for an agency to "speak with one voice." Of interest, our results for two of the regulation lakes contrast to those of Shroyer et al. (2003). Shroyer et al. (2003) used a before-and-after–control-and-impact experimental design with two regulation lakes (Ann and Bavaria) and control lakes (Pierson and Zumbra). In our study, Ann Lake had a high posterior median lake effect, and Bavaria Lake had the highest posterior median lake effect for the lakes studied, suggesting that size structure improvements in these populations were highly likely. While Shroyer et al. (2003) noted that largemouth bass PSD increased in Ann and Bavaria lakes, they detected no statistically significant treatment effects, likely due to a low sample size and fluctuations in all four lakes. However, some anglers expressed positive opinions regarding the regulation and cited a perceived increase in the catch rates of larger sized largemouth bass. Creel data analyzed by Shroyer et al. (2003) revealed that harvest rates of largemouth bass declined and catch rates increased during the regulated time period; however, differences between time periods were not statistically significant. The management decision regarding the largemouth bass catch-and-release regulation on Bavaria Lake was to remove the catch-and-release regulation and change regulations back to the statewide regulation, which was a bag limit of six fish with no length limit (Table 3).

Individual propensities in perceiving success of regulations can also be the result of multiple goals, regional differences, and other factors. Increasingly, specific and quantifiable goals are specified for new regulations, but no such criteria were provided with our survey. In completing the survey questionnaire, fisheries biologists had to base their judgment on limited biological survey data. Regional differences in biological factors (such as largemouth bass growth, population size structure, prey densities, and species interactions) may affect where regulation objectives are met and concomitantly influence biologists' perceptions of success. Individual propensities to consider regulations successful may also reflect ideas about how large a response would have to be before local anglers would consider it successful. Further, importance of a fishery to biologists and anglers within a region may influence perceptions. The slightly pessimistic or cautious effect for region 1 nonsupervisors may thus reflect less interest in length regulations in the part of the state with many lakes and farthest from urban centers. Post et al. (2008) noted that perspectives from managers in areas of rich fisheries resources and lower densities of anglers might be different than those from urban fisheries managers. Nevertheless, the relatively large variance in individual propensities to judge regulations successful demands further exploration. Open-ended questions about how decisions were reached could be asked in some future surveys, or focus-group discussions may be used to explore this.

Finally, there may or may not be a disconnect between the biological inferences derived from statistical measures of fish stock data used to evaluate regulations and the sociological constraints and values that must be addressed when promulgating regulations (DeStefano and Steidl 2001; Arlinghaus 2006). Fisheries biologists must consider a variety of issues associated with managing fisheries using length limits that may influence their perceptions of regulation success, not the least of which are the social and political implications of continuing or rescinding a regulation (Malvestuto and Hudgins 1996). In managing fisheries, multiple goals, however clearly stated, allow ambiguous possible outcomes, where regulations succeed by only some criteria. Goals are rarely specified in terms of angler success or satisfaction, though agency staff always consider angler views in evaluating regulations, however few or biased the contacts may be. More information on angler support and perceptions of regulations can be useful in determining communications needs and in recognizing potential conflicts regarding regulation change (Quinn 1992; Brown 1996; Jakus et al. 1996; Arlinghaus 2005). In searching for the right regulation for the right situation, there is an apparent need to determine if regulations improve fisheries, as judged by both biologists and anglers, and to link these judgments and perceptions to fishery survey measures of length frequency changes, as well as to understand how angler motivations and angler typology influence these perceptions (e.g., Chipman and Helfrich 1988; Gigliotti and Peyton 1993; Ditton 1996). While creel surveys are rarely used to assess length limit efficacy to improve angling, a similar approach using questionnaires with anglers, as was used here with fisheries biologists, may yield informative data on what constitutes an improved or high quality fishery. For example, researchers could survey bass anglers in a high-density bass fishery region of a state or province to ask if the quality of the size structure of the bass population was high. This question would be repeated for a set of lakes, such that each angler would contribute a perspective for many lakes, and a statistical model would include both an angler effect and a lake effect. Researchers could then look for associations between modeled lake effects and length frequency distributions from electrofishing surveys. If any relationship existed, the understanding of conditions that anglers find satisfying could be linked to actual fishery conditions measured by fisheries biologists. This could be one step in developing a quantitative approach for assessing regulations that is based on angler satisfaction measures.

Acknowledgments

We thank Andrew Carlson and Dan Isermann for advice and review of earlier drafts of the manuscript. We thank Minnesota fisheries biologists for completing questionnaires. This project was funding in part by the Federal Aid in Sport Fish Restoration (Dingell–Johnson) program. Three formal reviewers improved the manuscript.

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Appendix: WinBUGS code

The WinBUGS code for the preferred hierarchical model to predict the response for improvement for a largemouth bass fishery under three different regulation types as judged by biologists, using the survey data set, is as follows:

```
Model     {
          # pe[ k ] - person code (1, 2, ..., 73)
          # mc[ ] - biologist professional class code (2=supervisor; 1=non-supervisor)
          # lake[ i ] - lake code (1, 2, ..., 19)
          # tg[ j ] - treatment group (1=control; 2=12-in max; 3=catch-and-release)
          # r[ k ] - region (1, 2, 3, 4)
          # y[ ] - response to first question (1=improved; 0=nonimproved).
          # Prior on precision of random effect for person in group
          sigmag ~ dunif(0,10)
          taug <- 1/(sigmag*sigmag)

          for (k in 1:73) {
              # Random effect for propensity of biologist k
              gamma[ k ] ~ dnorm(0, taug)
          }

          # Hyperprior on treatment probability of success based on Wilde (1997);
          # then mu[ j ] = logit(eta[ j ])
          eta[ 1 ] ~ dbeta(1,1)
          eta[ 2 ] ~ dbeta(30,11)
          eta[ 3 ] ~ dbeta(30,11)
          sigmat ~ dunif(0,10)
          taut <- 1/(sigmat * sigmat)
          for ( j in 1:3) {
              mu[ j ] <- log(eta[ j ] / (1 - eta[ j ]))
          }
          # Random effect for lake i (depending on treatment of lake i)
          for (i in 1:19) {
              theta[ i ] ~ dnorm(mu[tg[ i ]], taut)
          }

          # The likelihood part
          for (h in 1:1387) {
              logit(p[ h ]) <- theta[lake[ h ]] + gamma[pe[ h ]]
              y[ h ] ~ dbin(p[ h ], 1)
          }
}
```