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[Article]

Experimental Analysis of a Reduced Daily Bluegill Limit in Minnesota

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Abstract.—The effect of a reduced daily limit (from 30 to 10 fish/d) on the size structure of bluegills *Lepomis macrochirus* in eight Minnesota lakes was measured with a controlled and replicated experiment. Bluegills from four treatment lakes (daily limit of 10 fish) and four control lakes (daily limit of 30 fish) were sampled in 2 years prior to regulation implementation and in the fourth and fifth years after regulation implementation. Repeated-measures analysis of variance was used to test for changes in two measures of size structure: mean length and 90th percentile length. The mean length of bluegills sampled in trap nets was significantly greater in treatment lakes than in control lakes at the end of the experiment. Bluegill 90th percentile lengths were higher during the postregulation period than the preregulation period, but not significantly so (although the *P*-value approached significance). Postregulation increases in length at maturity and growth rate were observed in the treatment lakes that exhibited the strongest responses in size structure. Results of the experiment suggest that regulations designed to significantly reduce angling harvest have potential for improving bluegill size structure.

The size structure of bluegills *Lepomis macrochirus* in Minnesota lakes has progressively worsened in the past several decades. Numbers of large (>200 mm) bluegills have declined in the harvest (Cook and Younk 1998), as have numbers of trophy (>250 mm) bluegills (Olson and Cunningham 1989). Greater angling exploitation is an important reason for the decline in bluegill size (Coble 1988). Although several attempts have been made to improve bluegill size structure in Minnesota, they have usually been directed at reducing density and increasing growth rates (Scidmore 1959; Davis 1979, 1985; Cross et al. 1992) and not at reducing angling exploitation. Results have been short lived and not cost effective, and are not in widespread use in the state. Attempts at improving size structure by directly regulating bluegill harvests have been principally investigated with simulation models (Beard et al. 1997).

In addition to the direct population dynamic effects of angling mortality, the phenotypic plasticity of life history traits of parental male (and female) bluegills can compound the effects of angling on size structure (Beard and Essington 2000). For example, the continual removal of large, parental males by angling causes the remaining male bluegills to mature at smaller sizes and earlier ages (Jennings et al. 1997). Growth rates decline with the earlier maturation schedule because a significant amount of energy that previously went to somatic growth is, upon maturity, allocated to gonadal development and reproductive activity. In addition, mortality rates can increase when teleosts mature (Roff 1984). These costs of reproduction have a limiting effect on bluegill size structure, probably setting an upper bound on size distributions. In Minnesota, populations with the largest bluegills are associated with the lowest fishing effort and the largest size at maturity (Drake et al. 1997).

In an effort to improve bluegill size structure in Minnesota lakes, an experiment was initiated to investigate the effects of a regulation designed to reduce the harvest of bluegills. It was hypothesized that the reduction in harvest would benefit bluegill size structure both by the direct effects of lower mortality and by increasing size at maturity, which in turn produces higher growth rates and lower mortality rates. Although several regulations were considered, such as length and season restrictions and limited entry, a daily limit reduction was selected based on several characteristics important to the bluegill fishery in Minnesota. The simplicity of a daily limit regulation allows the general fishing public to understand and comply, and thus is particularly important to the many panfish anglers that are children or occasional anglers. Simple regulations are more enforceable and probably result in higher rates of compliance. Daily limit regulations have more potential for widespread use than management options such as limited entry. Also, daily limits do not cause the angling op-

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TABLE 1.—Characteristics of eight Minnesota lakes included in an experiment on the effect of daily limit reduction on bluegill size structure. Asterisks denote treatment lakes; unmarked lakes were controls. Angling pressure and harvest data were measured during creel surveys in 1994 and 1995.

Lake	Latitude	Longitude	Area (ha)	Maximum depth (m)	Total alkalinity (mg/L as $CaCO_3$)	Secchi depth (m)	Summer angling pressure (angler-hours/ha)	Summer bluegill harvest (kg/ha)	Percent of harvest ≥ 200 mm
Bass	45°19′N	94°06′W	88	10.4	148	4.6	115	2.1	0.8
Beaver	45°24′N	94°14′W	62	8.2	150	2.7	80	6.4	1.1
Carnelian*	45°22′N	94°16′W	66	11.0	140	3.4	106	4.5	0.0
May	47°05′N	94°36′W	76	15.2	128	4.9	55	1.0	0.7
Ox Yoke*	46°52′N	94°28′W	67	12.8	102	5.2	61	3.2	1.0
Pleasant*	45°29′N	94°17′W	90	10.1	138	1.6	122	11.5	0.2
Sanburn*	46°50′N	94°27′W	94	14.6	103	5.2	78	4.6	1.8
Widow	46°55′N	94°20′W	73	14.0	94	3.7	101	6.0	1.9

portunity reductions that are inherent to season restrictions and limited-entry systems (a highly valued attribute of fishing in Minnesota is the abundant availability of angling opportunities). Because daily limit regulations have been ineffective in reducing harvest in many applications (most anglers rarely achieve a large limit: Noble and Jones 1993), a significant reduction in the daily limit is necessary for the regulation to be effective. The daily limit of sunfish (bluegills and pumpkinseeds *Lepomis gibbosus*) on lakes statewide was 30 fish. Potential harvest reductions were calculated by truncating daily catch distributions from completed-trip creel survey interviews conducted at study lakes. A daily limit of 10 sunfish was estimated to reduce annual bluegill harvest by 39% and was selected for the experiment.

Study Area

Eight lakes in Minnesota were used in the experiment (Table 1). All lakes had similar physical and chemical characteristics: generally small in size, moderate depth, relatively clear water, and poor bluegill size structure (few fish > 200 mm in the harvest). All eight lakes had moderate levels of vegetation dominated by plant genera common in Minnesota: muskgrasses *Chara* spp., coontails *Ceratophyllum* spp., yellow water lilies *Nuphar* spp., pondweeds *Potamogeton* spp., and bulrushes *Scirpus* spp. Dominant predators included northern pike *Esox lucius* and largemouth bass *Micropterus salmoides*. Walleyes *Sander vitreus* were generally not abundant in these lakes, although small populations were maintained through stocking. Pumpkinseeds, black crappies *Pomoxis nigromaculatus*, yellow perch *Perca flavescens*, and yellow bullheads *Ameiurus natalis* were also important members of the fish communities. The study lakes are typical of hundreds of similar Minnesota lakes that provide important panfish opportunities for anglers.

Methods

The experimental design consisted of a before–after, control–treatment method that involved replication in time and in space (Underwood 1992; von Ende 1993). The replication in time consisted of sampling 2 years before and in the fourth and fifth years after regulation implementation. Replication in space consisted of sampling four treatment lakes (daily limit of 10 sunfish) and four control lakes (daily limit of 30 sunfish). This design had full spatial replication of both control and treatment groups, which differs from typical before–after, control–impact designs (Green 1979; Stewart-Oaten et al. 1986; Underwood 1992, 1994) used to detect environmental impacts of stressors with only one spatial treatment (e.g., a power plant, factory effluent, or other large-scale disturbance that would be unrealistic to replicate spatially).

A univariate repeated-measures analysis of variance (ANOVA; von Ende 1993) was used to detect differences in bluegill size structure before and after the regulation was implemented and between regulation and control lakes. The mean length of bluegills in trap nets was the primary response variable. Treatment was a categorical variable equal to regulation or control, and period was the before and after variable. The before period was defined as the 2 years (1995 and 1996) before regulation implementation (although the regulation was implemented on March 1, 1996, significant harvest did not occur until after sampling in May). The after period was defined as the fourth and fifth years after regulation implementation (2000 and 2001), which allowed three intermediate years of change to occur. The repeated

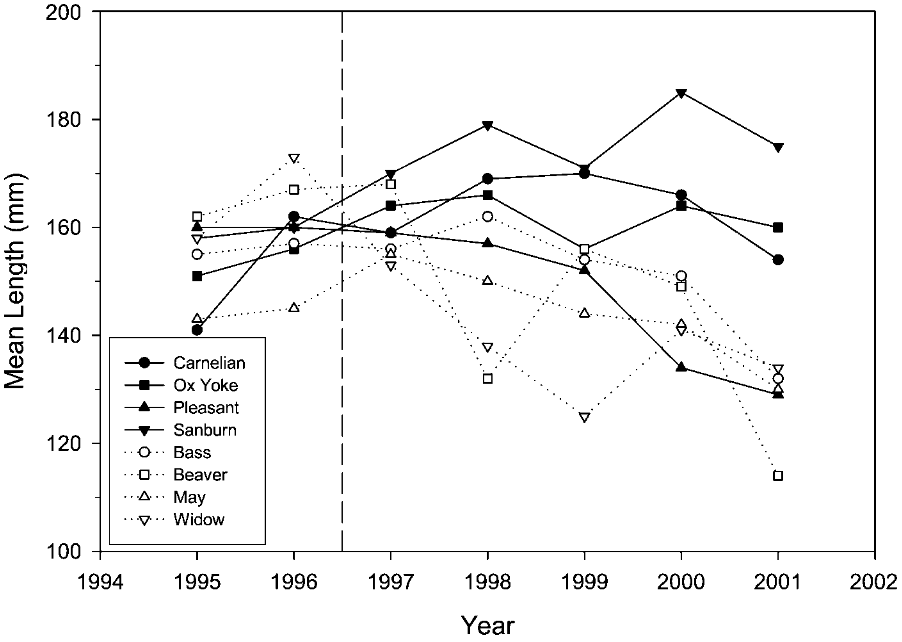

FIGURE 1.—Mean length of bluegills sampled in spring trap nets from eight Minnesota lakes during 1995–2001. Regulation lakes (those with daily limits reduced from 30 to 10 sunfish/d) are represented by solid lines; control lakes are represented by dotted lines. The year of regulation implementation is represented by the vertical dashed line.

measure consisted of the annual mean lengths measured in each of the two years within each period. The interaction term between period and treatment in the ANOVA was the specific test of significance for the experiment (i.e., did pre- and postregulation size structure differ more in regulation lakes than in control lakes?). A 0.10 level of significance was used (an α level common in large-scale ecological experiments: Scheiner 1993). SYSTAT software version 8.0 (Wilkinson 1998) was used for the ANOVA. In addition, a second response variable, the 90th percentile length (the length that 90% of sampled fish are less than), was used as a measure of the large-fish component of size structure. Repeated-measures ANOVA was used to test changes in 90th percentile length as well.

Repeated-measures ANOVA could not be used to test the significance of changes in length at maturity, age at maturity, and growth rate because only one preregulation (1996) and one postregulation (2001) estimate existed for those variables. Instead, two-sample, equal-variances *t*-tests of pre- and postregulation differences were used to detect significant changes in length at maturity, age at maturity, and growth rate. Only parental males were examined in tests for growth and maturity changes.

Bluegills were sampled annually with 19-mm trap nets in late May (just prior to spawning; water temperature = 15–20°C). Between 6 and 10 overnight sets were made on the shoreline of each lake; the sample size goal was 150 bluegills. In addition to length information, scales, sex, and maturity data were collected in 1996 (preregulation) and in 2001 (postregulation). Ten bluegills per 10-mm length interval were aged based on scales, and their sex and level of maturity were determined by dissection and direct observation of gonads in the body cavity. The 50% length at maturity and 50% age at maturity were estimated by use of probit analysis (Welch and Foucher 1988).

Results

The mean length of bluegills increased in three of the regulation lakes (Carnelian, Ox Yoke, and Sanburn) and decreased in all four control lakes during the period after regulation implementation (Figure 1). Bluegills in the fourth regulation lake (Pleasant) decreased in mean length after the regulation was implemented. The general trend of decreased mean size of bluegills in control lakes was probably due to the effect of the weak year-classes of 1992 and 1993 (Tomcko and Pierce 1997), which resulted in low numbers of small bluegills

TABLE 2.—Univariate repeated-measures ANOVA results of an experiment measuring the change in mean bluegill length (response variable) after implementation of a reduced daily limit in Minnesota lakes (treatment) based on before and after (period) measurements (repeated). Abbreviations are as follows: SS = sum of squares; MS = mean square.

Source	SS	df	MS	*F*	*P*
Between subjects					
Treatment	833.3	1	833.3	3.550	0.109
Error	1,408.3	6	234.7		
Within subjects					
Period	676.2	1	676.2	2.279	0.182
Period × treatment	1,129.3	1	1,129.3	3.807	0.099
Error (period)	1,779.9	6	296.6		

in the early years of the study and higher numbers of small bluegills in later years, after recruitment increased. Overall, mean length in the postregulation period was significantly greater ($P = 0.099$) in treatment lakes than in control lakes (Table 2).

Size structure changes, as measured by the 90th percentile lengths, illustrated an improvement in the upper portion of the bluegill length distribution for Carnelian and Sanburn lakes (Table 3). The 90th percentile length of bluegills sampled in Carnelian Lake increased from 167 mm in 1995 to 195 mm in 2000. In Sanburn Lake, the 90th percentile length increased from 185 mm in 1995 to 209 mm in 2000. Bluegills in Ox Yoke Lake exhibited a small increase in the 90th percentile length, and bluegills from Pleasant Lake did not show any improvement. The 90th percentile lengths in control lakes exhibited no consistent trends. Although the period × treatment interaction term in the repeated-measures ANOVA for 90th percentile length was not statistically significant ($P = 0.155$), the magnitude of the *P*-value suggested that biological processes affecting large fish might have been occurring in treatment lakes.

A significant increase (*t*-test, $P = 0.04$) in parental male length at maturity was observed in treatment lakes after the regulation was implemented (Table 4). The populations in lakes that saw the largest improvements in size structure (Carnelian and Sanburn lakes) experienced the largest increases in length at maturity (50% length at maturity increased by more than 20 mm). Length at maturity in the other two treatment lakes (Ox Yoke and Pleasant) also increased, but by approximately the same magnitude as that observed for some of the control lakes.

The growth rates of bluegills (as measured by parental male length at age 7) increased in all of the study lakes after regulation implementation (Table 5). Changes in growth rates in regulation lakes were not significantly different from changes in growth rates in control lakes (*t*-test, $P = 0.26$), although the absence of 7-year-old parental males in Beaver Lake samples during 2001 decreased the power of the test. Also, the large growth rate increase in May Lake (a control) was unexpected. However, the lakes with the largest size structure responses (Carnelian and Sanburn lakes) exhibited the largest growth increases among the treatment lakes. The increase in parental male length at age 7 in Sanburn Lake, from 164 mm in 1996 to 200 mm in 2001, was especially large.

The age at maturity of parental males decreased in all lakes between 1996 and 2001 (Table 6). However, changes were not significant when regulation lakes were compared to control lakes (*t*-

TABLE 3.—Ninetieth percentile lengths (mm) of bluegills sampled in spring trap nets from four Minnesota lakes with reduced daily limit regulations and four control lakes in two pretreatment years (1995–1996) and two posttreatment years (2000–2001).

Lake	Treatment	1995 (*N*)	1996 (*N*)	2000 (*N*)	2001 (*N*)
Bass	Control	176 (250)	179 (143)	176 (149)	171 (154)
Beaver	Control	179 (299)	185 (143)	185 (123)	152 (163)
May	Control	166 (284)	171 (189)	185 (159)	176 (209)
Widow	Control	186 (306)	194 (177)	167 (148)	169 (153)
Carnelian	Regulation	167 (301)	184 (140)	195 (103)	190 (167)
Ox Yoke	Regulation	180 (296)	188 (226)	192 (147)	184 (161)
Pleasant	Regulation	180 (303)	177 (243)	175 (76)	169 (152)
Sanburn	Regulation	185 (297)	187 (169)	209 (144)	203 (187)

TABLE 4.—Change in 50% length at maturity (mm; 95% confidence intervals in parentheses) of parental male bluegills sampled from four Minnesota lakes with reduced daily limit regulations and four control lakes in 1996 and 2001.

Lake	Treatment	50% length at maturity		Change (mm)
		1996	2001	
Bass	Control	149 (143–154)	164 (158–169)	15
Beaver	Control	152[a]	152 (139–229)	0
May	Control	135 (123–143)	144 (128–151)	9
Widow	Control	156[a]	155 (127–159)	−1
Carnelian	Regulation	152 (147–156)	177 (167–183)	25
Ox Yoke	Regulation	152[a]	165 (153–173)	13
Pleasant	Regulation	152 (146–163)	160 (149–166)	8
Sanburn	Regulation	145[a]	174 (167–178)	29

[a] Confidence interval estimation did not converge.

test, $P = 0.84$). The decreased age at maturity was probably due to the increased growth rates observed for all lakes.

Discussion

Although the results were somewhat equivocal, the experiment did suggest that a large (at least 40%) reduction in harvest does have the potential to improve bluegill size structure. The reduced daily limit in treatment lakes was associated with significantly higher mean lengths than were observed in control lakes, but changes in 90th percentile length were not significant (although the *P*-value approached significance). The magnitude of size structure changes was enough to be detected by anglers in at least two of the treatment lakes (Sanburn and Carnelian) and possibly a third (Ox Yoke Lake), where the number of bluegills greater than 180 mm increased and where some fish exceeded 200 mm in postregulation years. These increases occurred in bluegill size ranges that anglers find desirable. Although the responses of the treatment lakes were variable, the existence of this variability was the fundamental reason for the replicated and controlled experiment: testing of an overall regulation effect in the face of inter-lake variability.

TABLE 5.—Change in length (mm) at age 7 of parental males sampled from four Minnesota lakes with reduced daily limit regulations and four control lakes in 1996 and 2001.

Lake	Treatment	Length at age 7		Change (mm)
		1996 (*N*)	2001 (*N*)	
Bass	Control	161.1 (16)	164.0 (6)	2.9
Beaver	Control	168.5 (17)		
May	Control	148.5 (14)	175.7 (15)	27.2
Widow	Control	172.4 (10)	180.2 (9)	7.8
Carnelian	Regulation	173.1 (18)	194.8 (4)	21.7
Ox Yoke	Regulation	166.6 (13)	181.0 (10)	14.4
Pleasant	Regulation	167.5 (10)	173.3 (7)	5.8
Sanburn	Regulation	164.0 (6)	200.0 (3)	36.0

The significant increase in male bluegill length at maturity after the regulation was implemented may be the most important finding of the study. The higher growth rates exhibited by bluegills that were able to direct energy into somatic growth rather than gonadal development and reproductive activities had direct consequences for size structure. The improvements in size structure were greatest for populations that experienced the largest increases in male length at maturity. Phenotypic plasticity of size at maturity is common in fish and probably evolved as a life history response to environmental stress (Stearns and Crandall 1984). Optimal size at maturity is a function of growth rate, mortality rate, and reproductive competition processes. Size at maturity of male bluegills in this study appeared to be more important than age at maturity. The behavioral and ecological processes that operate on bluegill maturation are size, not age, related. In sunfishes, females deposit eggs in nests guarded by the largest males (Jennings and Phillip 1992). Size at maturity then becomes an important consideration for male sunfish and is the characteristic that most directly reveals the effect of phenotypic maturation plasticity on the size structure of bluegills. Although not measured in this study, female bluegill size at maturity would also be expected to increase due to the more traditional growth, mortality, fecundity, and maturity tradeoffs of teleosts (Roff 1984).

Several questions remain concerning greater application of the daily limit reduction. The first relates to the apparent benefit of the regulation in some lakes and not others. There are several possible reasons for the variable response. One is that the daily limit of 10 fish might not restrict harvest sufficiently in some lakes to stimulate a response

TABLE 6.—Change in 50% age at maturity (years; 95% confidence intervals in parentheses) of parental male bluegills sampled from four Minnesota lakes with reduced daily limit regulations and four control lakes in 1996 and 2001.

Lake	Treatment	50% age at maturity		Change (years)
		1996	2001	
Bass	Control	6.70 (6.18–6.97)	6.45 (5.76–7.12)	−0.25
Beaver	Control		6.84[a]	
May	Control	6.73 (6.04–7.10)	5.04 (4.35–5.54)	−1.69
Widow	Control	6.11[a]	5.06[a]	−1.05
Carnelian	Regulation	6.13 (2.97–6.80)	5.89 (5.31–6.41)	−0.24
Ox Yoke	Regulation	6.83 (6.22–7.29)	6.42 (5.35–7.02)	−0.41
Pleasant	Regulation	6.36 (6.09–6.73)	5.25 (4.84–5.81)	−1.11
Sanburn	Regulation	6.58 (5.96–7.03)	4.82[a]	−1.76

[a] Confidence interval estimation did not converge.

in size at maturity. For example, the treatment lake with the smallest change in bluegill size (Pleasant Lake) had the largest city nearby (8 km from St. Cloud, Minnesota, population 58,000) and experienced the highest bluegill harvest (over 11 kg/ha in the summer; Table 1). The daily limit of 10 fish might not have reduced angling mortality sufficiently for that level of harvest. Another possible reason for variable results could be uneven regulation compliance. Although no estimates of compliance were available, higher rates of noncompliance on a heavily used lake like Pleasant Lake could significantly reduce regulation benefits (Gigliotti and Taylor 1990). It is also possible that more time would be required for some lakes to respond to the regulation. The last potential reason for the variable results is that changes in size structure were simply due to random variation and a type I error (measurement of a nonexistent treatment response; 10% probability in this experiment). Only future trials of daily limit reductions in more lakes will determine the basis for this variability.

Another concern that should be addressed before greater application of bluegill daily limit reductions relates to the redistribution of fishing effort after successful implementation of a regulation. A large increase in fishing pressure after an improvement in size structure could diminish the beneficial effects of a regulation. Cox and Walters (2002) modeled the effects of this type of angler behavior and suggested that special regulations may have to be implemented across a high proportion of available lakes to counteract the detrimental effects of shifts in fishing pressure. Future creel surveys may prove useful in measuring changes in angler behavior and fishing pressure.

Fisheries managers in Minnesota could consider daily limits even smaller than 10 sunfish/d. Catch distributions based on completed-trip creel surveys from the study lakes suggest that a daily limit of 5 sunfish would reduce the harvest by more than 50%. A reduction in harvest (and fishing mortality) of that magnitude might produce larger increases in size at maturity and benefit size structure even more than the 10-fish limit did, and in possibly more lakes. However, many anglers might not be interested in such a high tradeoff between harvest and bluegill size. Surveys of angler desires would be helpful in quantifying the harvest–size tradeoff in terms of angler satisfaction. In addition, reductions further than the 10-sunfish limit might be necessary depending on the daily catch distributions calculated for other lakes. The eight lakes in this study are typical of lakes where panfish are an important and targeted species, and each possesses a relatively saturated daily catch distribution (relatively large catches, including some limits). Other lakes in Minnesota for which panfish are not the most sought-after species have daily catch distributions that contain fewer large values, and would require smaller daily limits to achieve a desired reduction in harvest. In any case, completed-trip interviews from creel surveys would be essential data in the formulation a daily limit regulation.

The use of a formal experiment with replication and control sites worked well for this study and was a significant improvement over the case history method of regulation evaluation commonly used in Minnesota and elsewhere. However, one issue that remains a concern when designing an experiment of this type relates to the independence of samples. It is difficult to achieve the requirement of independent before and after samples in an experiment designed to measure a response in fish that have any degree of longevity. For example, to achieve true independence in this study, samples should have been taken in randomly selected years from before and after periods sufficiently long enough to allow for independence (e.g., at least two generations). Given the generation time of bluegills in Minnesota (about 8 years), combined with at least 3 years of transition time (and more would certainly be better), the experiment would require at least 35 years to complete if two pretreatment and two posttreatment samples were used (more samples would require an even longer experiment). Few natural resource agencies have the ability or patience to run an experiment that long. As Underwood (1994) concluded, much more research is needed to fully understand the consequences of the common reality of nonindependent samples in environmental experiments.

In conclusion, the results of the experiment suggest that fisheries managers can take advantage of the maturation plasticity of bluegills and can manipulate mortality schedules to increase size at maturity, thereby improving size structure. Daily limits of 10 fish have potential for increasing the mean length of bluegills in bass and panfish lakes in Minnesota. The potential for application of reduced daily limits for lakes in other states is unknown. However, north-temperate, natural lakes that possess population and fishery characteristics similar to those of the study lakes may be good candidates for large daily limit reductions. The key consideration would be that catch distributions from completed-trip creel surveys indicate harvest reduction by at least 40% from a daily limit reduction.

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