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Effects of Length Limits on Muskellunge in Bone Lake, Wisconsin

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Abstract.—Minimum length limits are a commonly used management tool for protecting fisheries from exploitation and for improving population size structure. However, little is known about the effects of minimum length limits on populations of muskellunge *Esox masquinongy*. We monitored changes in the muskellunge population in Bone Lake, a 1,781-acre lake in northwest Wisconsin over a 31-year period (1964–1995) during which time length limits were changed from 30 in to 34 in and from 34 in to 40 in. These changes were compared with population changes in nearby Deer Lake (807 acres), where the length limit remained at the statewide minimum of 32 in. Mean length of adult muskellunge in Bone Lake increased from 31.3 in in 1964 to 36.0 in in 1995. Adult (≥30-in) muskellunge abundance in Bone Lake increased more than five-fold during the study and reached a density of 0.99 fish/acre. Abundance of larger (≥38-in) muskellunge increased 269% following minimum length limit increases between 1982 and 1995. Relative weight (W_r) of Bone Lake muskellunge decreased during the study, suggesting intraspecific competition for food resources. The muskellunge population in Deer Lake also had positive increases in size structure, but the increases were not as great as those in Bone Lake, and population abundance did not change. Results from this study suggest that high minimum length limits can increase abundance and mean length of a muskellunge population, but biologists need to consider long-term effects on the fish community if high densities are achieved.

The use of minimum length limits to protect certain size-classes of fish is a commonly used fisheries management tool (Everhart and Youngs 1981). High minimum length limits have been used in the management of populations of muskellunge *Esox masquinongy* to develop trophy fisheries (Hanson 1986). Unfortunately, the response of muskellunge populations to length limits is rarely quantified. The reason for this lack of evaluation are probably twofold: (1) muskellunge commonly occur at low densities, which makes sampling efforts and statistical interpretations difficult (Hanson et al. 1986a) and (2) longevity of muskellunge (e.g., up to 30 yrs; Casselman and Crossman 1986) requires a considerable response time to any regulation change.

The muskellunge population in Bone Lake, Wisconsin, was amenable to evaluation of length limits for several reasons. First, muskellunge in Bone Lake occur at relatively high densities compared with other Wisconsin waters, which makes sampling adequate numbers of fish possible. Second, comparable sampling protocol occurred at several intervals over a 31-year period (1964–1995), during which two length limit changes occurred. Third, comparable population data were collected on a nearby, similar lake (Deer Lake) that could serve as a control because there were no length limit changes during a 5-year period within the sampling period of Bone Lake. Objectives of this study were to monitor changes in the muskellunge population in Bone and Deer lakes in response to changes in minimum length limits. Specifically, we were interested in changes in population size structure and abundance and individual fish length and condition.

Study Sites

Bone and Deer lakes are in northwest Wisconsin, both within 50 mi of Minneapolis–St. Paul, Minnesota. Both lakes are mesotrophic to eutrophic and have shorelines almost completely developed with permanent and seasonal dwellings. Fish communities in both lakes include muskellunge, largemouth bass *Micropterus salmoides*, bluegill *Lepomis macrochirus*, pumpkinseed *L. gibbosus*, black crappie *Pomoxis nigromaculatus*, yellow perch *Perca flavescens*, white sucker *Catostomus commersoni*, bullheads *Ameiurus* spp., and golden

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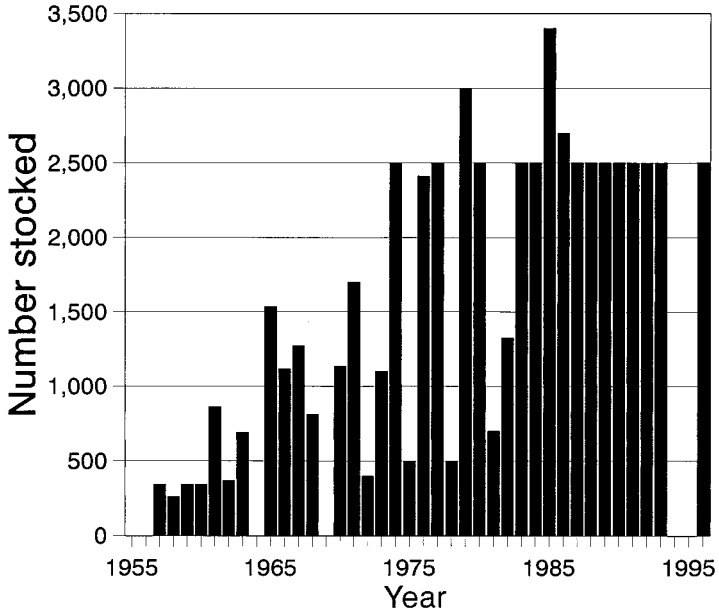

FIGURE 1.—Numbers of fingerling muskellunge (≥9 in) stocked into Bone Lake, Wisconsin, 1955–1995. No stocking occurred in 1994 or 1995.

shiner *Notemigonus crysoleucas.* Northern pike *E. lucius* and walleye *Stizostedion vitreum* are present in low numbers.

Bone Lake is a 1,781-acre drainage lake with a maximum depth of 43 ft and a mean depth of 22 ft. Bone Lake has been managed for muskellunge since 1935. Natural reproduction of muskellunge is poor, so the population is largely maintained by stocking. Before 1955, most stocking consisted of either fry or small fingerlings (<5 in). As culture techniques improved, large (≥9 in) fingerlings were stocked through the 1960s and 1970s (Figure 1). Stabilized hatchery production in the 1980s allowed for an annual quota of 2,500 large (≥9 in) fingerlings (1.4 fish/acre).

Deer Lake is a 807-acre seepage lake with a maximum depth of 46 ft and a mean depth of 26 ft. Muskellunge were initially stocked into Deer Lake in 1967. Before 1979, most muskellunge stocking consisted of hybrid tiger muskellunge (northern pike × muskellunge). Natural reproduction of muskellunge in Deer Lake is poor, so the population is maintained by stocking. The annual stocking quota for Deer Lake was 1,600 large fingerlings (2.0 fish/acre).

Methods

Several regulation changes occurred during this study. The statewide minimum length limit for muskellunge in Wisconsin was 30 in from 1935 until 1983, when it was increased to 32 in. In 1983, the minimum length limit was changed to 34 in on 10 lakes, including Bone Lake, on an experimental basis. Also, in 1983, the opening day for muskellunge fishing was changed from the first Saturday in May until the Saturday closest to Memorial Day to protect muskellunge from harvest during the spawning period, which extended into late May in some northern Wisconsin waters (Hanson 1986). In 1990, the minimum length limit was again increased on Bone Lake to 40 in. Deer Lake remained under the statewide minimum (32 in) during the period 1988–1993.

We monitored changes in population size structure, abundance, and biomass and individual adult muskellunge length and condition in Bone Lake at five intervals over a 31-year period, 1964–1995. Sampling periods on Bone Lake were: 1964–1965, 1982–1983, 1985–1986, 1990–1991, and 1995–1996. Hereafter, sampling periods are referred to by only the first year of sampling. Raw data previously collected from Bone Lake in 1964–1965 (reported in Johnson 1971) were used to calculate certain variables and present a long-term perspective of changes in Bone Lake. Several population variables (abundance, size structure) were also monitored in the muskellunge population in Deer

Lake. Sampling periods on Deer Lake were 1988–1989 and 1993–1994.

Adult muskellunge were defined as sexually mature fish captured during the spring sampling period. For abundance estimates, a subsample of the adult population (≥30 in) were considered because of a systematic bias in sampling fish less than 30 in (Hanson 1986). We intended to monitor changes in growth rates; however, inherent problems with accurate interpretation of muskellunge scales (Johnson 1971; Casselman 1983; Fitzgerald et al. 1997) caused us not to use this variable in our study.

To determine population abundance, adult muskellunge were captured in two consecutive years using fyke nets (24-h sets) during the spring spawning period (Hanson 1986). Fyke nets had 4 × 6 ft frames with 1-in-bar mesh and leads from 50 to 100 ft. Muskellunge were measured to the nearest 0.1 in (total length) and marked with either a fin clip or preopercle tag (Johnson 1971). All muskellunge handled were sexed (when possible) by presence of eggs or milt or by visual inspection of the urogenital pore (LeBeau and Pageau 1989). Fish were also weighed to the nearest 0.1 lb during the first year of each sampling period.

Abundance of adult muskellunge was estimated using Bailey's modification of the Petersen method (Ricker 1975). Muskellunge captured in the first year were marked for recapture in the second year. Numbers of fish captured in the second year were adjusted for recruitment over a 1-year period using sex-specific growth rates. We used absolute growth rates from known-age fish for 1964, recapture of tagged individuals for 1982 and 1985, and growth rates from cleithrum interpretation for 1990 and 1995. Several independent estimates were calculated: (1) mature muskellunge of each sex 30 in and greater and (2) mature muskellunge, sexes combined, 30.0–33.9 in, 34.0–37.9 in, 38.0 in and greater, and 40.0 in and greater. Number of adult muskellunge 40 in and greater was determined from the proportion of muskellunge 40 in and greater handled in the marking run times the abundance estimate for fish 38 in and greater. Separate length-group estimates were not possible for 1964 because of small sample sizes in length categories. Biomass estimates were calculated by applying sex-specific weight–length relations from spring netting samples to length distributions and abundance estimates.

Size structure and condition of muskellunge were determined from spring-sampled fish. We used relative stock density (RSD) to describe population size structure (Anderson and Gutreuter 1983), with 30 in as stock size (Hanson 1986), and relative weight (W_r; Neumann and Willis 1994) to describe condition of muskellunge. (Relative stock density is the number of fish of a specified length and longer divided by the number of fish of stock length and longer, the result multiplied by 100. Relative weight is the ratio of a fish's weight to the weight of a ''standard'' fish of the same length.) We determined changes in population size structure using Kolmogorov–Smirnov tests, relative weight changes using analysis of variance (ANOVA), and changes in mean length using *t*-tests.

A roving creel survey was conducted on Bone Lake in 1982 and 1985. The creel survey began with the opening of fishing season and ended at freeze-up, which was usually several weeks before the official close of the muskellunge angling season. Little or no angling pressure occurred between freeze-up and the end of the muskellunge angling season, and muskellunge harvest during this period was therefore assumed to be zero. A creel clerk was assigned to half of the daylight hours 5 d/week. Shifts were defined as sunrise to midday or midday until one-half hour past sunset. One shift was scheduled each Saturday and Sunday, with the remaining three shifts scheduled randomly Monday through Friday. Five instantaneous counts were made during each shift on a stratified basis. An angler count was made at the beginning and end of the shift and at approximately 2-h intervals during the shift. Angler interviews were conducted during periods between instantaneous counts. Data were processed by the statewide creel survey program. Total angling effort was estimated for daylight hours only.

We supplemented creel survey data with voluntary registration at two cooperating resorts and one tavern and with angler reports of muskellunge caught in Bone Lake by members of Muskies, Inc. Voluntary registration was available to any angler wishing to record a catch on a chart. Information obtained through Muskies, Inc., included catch information from members only, hence some overlap between the two sources was recognized.

Results

In all, 4,202 adult muskellunge were sampled during the five sampling periods (10 years) in Bone Lake. The number of fish handled on an annual basis ranged from 190 to 887 (Table 1). Fyke net sampling effort ranged from 52 to 210 net lifts/year. Mean muskellunge catch per net lift (CPE)

TABLE 1.—Fyke-net effort, catch, and catch per unit effort (CPE) of muskellunge in Bone and Deer lakes, Wisconsin.

Lake and year	Effort[a] (net-nights)	Catch	CPE
Bone			
1982	196	489	2.5
1983	63	378	6.0
1985	133	887	6.7
1986	80	575	7.2
1990	52	435	8.4
1991	210	190	0.9
1995	154	409	2.7
1996	122	429	3.5
Deer			
1988	63	187	3.0
1989	20	163	8.2
1993	NR	226	
1994	NR	128	

[a] NR means effort not recorded.

was 4.7 and ranged from 0.9 to 8.4. In all, 704 adult muskellunge were sampled in Deer Lake during the two sampling periods (4 years). Number of muskellunge handled annually ranged from 128 to 226. Sampling effort for 1988 and 1989 was 63 and 20 net lifts and muskellunge CPE was 3.0 and 8.2, respectively. Net lifts were not recorded for Deer Lake during 1993 and 1994.

Length Frequency

The size structure of the muskellunge population in Bone Lake increased from 1964 to 1995 ($D = 0.52$, $P < 0.001$; Figure 2). Size structure increased between all sampling periods, except 1982–1985, when male muskellunge size structure remained similar ($D = 0.06$, $P = 0.23$) and female muskellunge size structure decreased ($D = 0.27$, $P < 0.01$). Mean length of muskellunge also increased from 1964 to 1995. Mean length of adult muskellunge increased from 31.3 in in 1964 to 36.0 in in 1995 ($t = 20.3$, df = 1,281, $P < 0.001$; Table 2). Most of the observed change in mean length occurred from 1964 to 1982 and again from 1985 to 1995. Mean length of males was similar in 1982 and 1985 and decreased significantly for females from 36.8 to 35.1 in ($t = 6.5$, df = 873, $P < 0.01$; Table 2).

Changes in mean length were greater for female muskellunge early in the study period and greater for male muskellunge later in the study period. From 1964 to1982, female muskellunge mean length increased 2.6 in, from 34.2 in to 36.8 in, while male muskellunge mean length increased only 2.1 in, from 29.4 in to 31.5 in (Table 2). In contrast, from 1982 to 1995, mean length of male

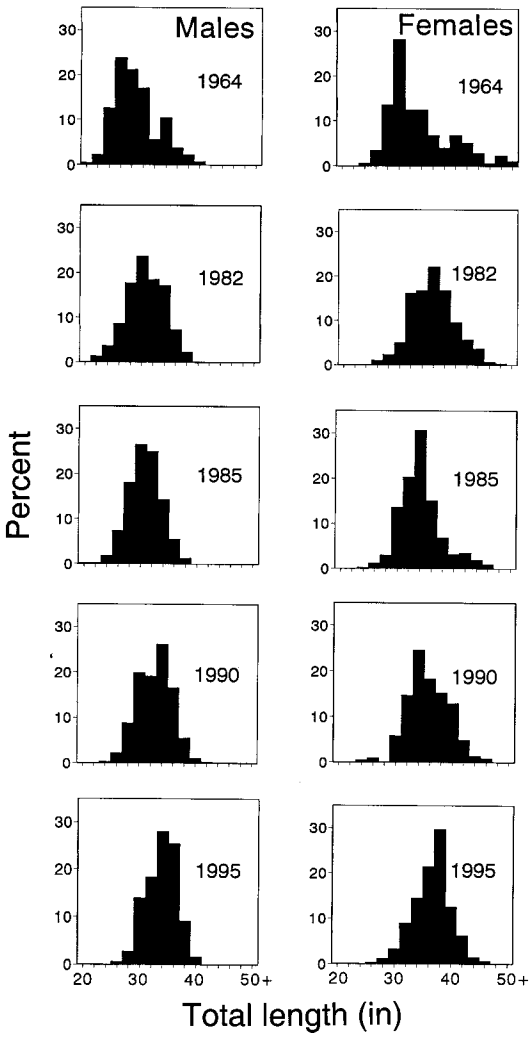

FIGURE 2.—Length frequency of adult muskellunge in Bone Lake, Wisconsin.

muskellunge increased 3.3 in, from 31.5 in to 34.8 in, while female muskellunge mean length increased only 0.9 in, from 36.8 to 37.7 in.

The muskellunge size structure in Deer Lake also increased during the 5-year period 1988–1993 ($D = 0.17$, $P < 0.001$). Mean length of adult muskellunge sampled in Deer Lake increased less than 1.0 in, from 34.8 in to 35.7 in (Table 2). Mean length of male muskellunge increased from 33.2 in to 34.5 in ($t = 5.4$, df = 416, $P < 0.001$), whereas the mean length of female muskellunge did not change ($t = 0.2$, df = 268, $P = 0.85$; Table 2).

Relative stock density for muskellunge 34 in and greater (RSD-34) increased from 47 in 1964 to 75

TABLE 2.—Mean (SE) total lengths (inches) of adult muskellunge sampled with fyke nets in Bone and Deer lakes, Wisconsin. Whole numbers centered beneath means are sample sizes.

Lake and year[a]	Male	Female	Sexes combined
Bone			
1964	29.4 (0.23)	34.2 (0.41)	31.3 (0.24)
	269	177	446
1982	31.5 (0.14)	36.8 (0.22)	33.4 (0.15)
	558	303	861
1985	31.7 (0.10)	35.1 (0.15)	33.0 (0.09)
	865	572	1,437
1990	33.6 (0.15)	36.7 (0.24)	34.7 (0.14)
	397	224	621
1995	34.8 (0.12)	37.7 (0.18)	36.0 (0.11)
	500	337	837
Deer			
1988	33.2 (0.19)	37.5 (0.28)	34.8 (0.19)
	218	132	350
1993	34.5 (0.15)	37.4 (0.25)	35.7 (0.15)
	216	138	354

[a] Year is first year of 2-year sampling period.

in 1995. The RSD-34 increased between all sampling periods, except from 1982 to 1985, when RSD-34 decreased from 56 to 46 (Table 3). Relative stock density for muskellunge 40 in and greater (RSD-40) was highest in 1964, decreased through 1985, and increased again in 1990. Deer Lake RSD-34 increased from 63 in 1988 to 77 in 1993, whereas RSD-40 decreased from 10 in in 1988 to 8 in in 1993 (Table 3).

Relative Weight

Relative weight of adult muskellunge declined across years and lengths. Mean W_r declined significantly from 110 in 1964 to 96 in 1995 (F = 22.3, df = 4, 1,659, $P < 0.001$; Figure 3). Mean

TABLE 3.—Abundance and size structure of adult muskellunge in Bone and Deer lakes, Wisconsin. Relative stock densities for fish 34 in and greater (RSD-34) and 40 in and greater (RSD-40) were computed using 30 in as minimum stock length.

Lake and year	Population estimate (CV)[a]	Fish per acre	Pounds per acre	RSD-34	RSD-40
Bone					
1964	325 (21.2)	0.18	2.4	47	14
1982	961 (7.7)	0.54	6.8	56	9
1985	1,499 (5.3)	0.84	9.5	46	5
1990	1,205 (12.8)	0.68	8.6	65	9
1995	1,757 (9.5)	0.99	13.2	75	10
Deer					
1988	730 (15.8)	0.90		63	10
1993	726 (14.5)	0.90		77	8

[a] Coefficient of variation (CV) = 100 × SD/mean.

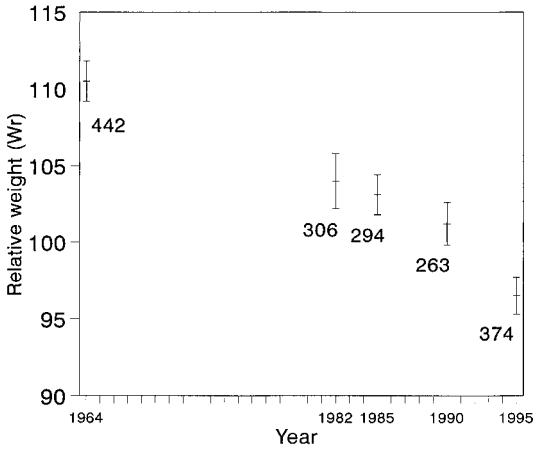

FIGURE 3.—Mean relative weight (W_r ± 95% confidence intervals) of adult muskellunge in Bone Lake, Wisconsin, 1964–1995. Numbers are sample sizes.

weight of a 37-in male muskellunge declined from 14.4 lb in 1964 to 13.5 lb in 1995, while the mean weight of a 40-in female muskellunge declined from 20.9 lb in 1964 to 18.3 lb in 1995 (Table 4). Mean relative weight (all years combined) declined significantly from 108 for fish less than 30 in to 99 for fish 38 in and greater (F = 4.8, df = 3, 1,659, $P < 0.01$; Figure 4).

Abundance

Abundance of adult muskellunge in Bone Lake increased 441% from 1964 to 1995 (Table 3). Den-

TABLE 4.—Weight of muskellunge in Bone Lake, Wisconsin, estimated from weight–length relations, 1982–1995.

Length and year	Weight (lb)		
	Male	Female	Sexes combined
34 in			
1964	11.8	13.1	13.0
1982	11.0	12.3	12.1
1985	11.1	12.0	12.1
1990	10.9	11.8	11.7
1995	11.0	11.7	11.3
37 in			
1964	14.4	17.0	16.4
1982	14.2	16.1	15.6
1985	13.7	16.1	15.8
1990	13.5	15.5	15.0
1995	13.5	15.0	14.5
40 in			
1964	16.9	20.9	19.7
1982	17.0	20.0	19.1
1985	16.3	20.3	19.4
1990	16.0	19.1	18.4
1995	16.1	18.3	17.6

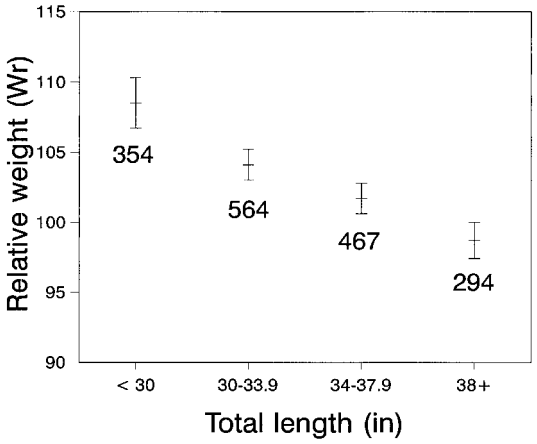

FIGURE 4.—Mean relative weight (W_r ± 95% confidence intervals) of muskellunge by length category in Bone Lake, Wisconsin. Numbers are sample sizes.

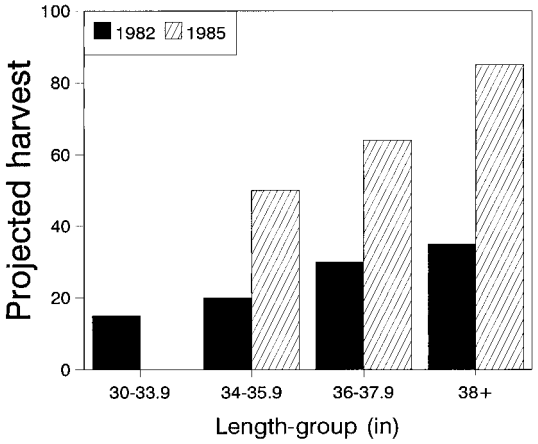

FIGURE 5.—Projected angler harvest (total number of fish) of muskellunge in Bone Lake, Wisconsin, following a length limit change from 30 to 34 in in 1983.

sity of adult muskellunge increased from 0.18 fish/acre to 0.99 fish/acre, and biomass increased from 2.4 lb/acre to 13.2 lb/acre (Table 3). Abundance increased between all sampling periods, except 1985 and 1990, when numbers decreased from 1,499 to 1,205. Male muskellunge abundance increased by 430%, and females increased by 453% (Table 5).

Muskellunge abundance increased for all length-groups from 1982 to 1995, except fish 30–34 in, which decreased by 10%. Abundance increased 126% for fish 34–38 in, 269% for fish 38 in and larger, and 158% for fish 40 in and larger.

From 1982 to 1985, larger fish (≥38 in) decreased, while abundance of muskellunge 30–38 in increased (Table 5). From 1985 to 1995, abundance of larger fish (≥38 in) increased while fish 30–34 in decreased, and fish 34–38 in remained similar through 1990, before increasing in 1995.

Abundance of adult muskellunge (≥30 in) in Deer Lake remained similar from 1988 to 1993 (Table 3). The number of fish 34–38 in increased 43%, and the number of fish 38 in and greater increased 58% (Table 5). Muskellunge abundance declined 56% in the 30–34-in length-group. The sex ratio shifted toward fewer males and more female muskellunge from 1988 to 1995 (Table 5).

Harvest

Angling effort, catch, and harvest increased on Bone Lake between 1982 and 1985. Fishing pressure for muskellunge increased 26%, from 14.8 h/acre in 1982 to 18.7 h/acre in 1985 (Table 6). Catch and harvest rates also increased during this period 13% and 50%, respectively. Harvest of muskellunge increased 99% in spite of the 34-in length limit implemented in 1983. Exploitation was 10.4% in 1982 with a 30-in minimum length limit (u = 100/961) and 36% in 1985 with a 34-in length limit (u = 199/553) (Figure 5).

Release of caught muskellunge recorded on resort charts by anglers supported the contention of

TABLE 5.—Abundance estimates of adult muskellunge by sex and length-group for Bone and Deer lakes, Wisconsin. Coefficient of variation (CV = 100 × SD/mean) is in parenthesis.

Lake and year	Sex		Length-group (in)			
	Male	Female	30–33.9	34–37.9	≥38.0	≥40.0
Bone						
1964	175 (33.0)	150 (25.3)				
1982	493 (9.6)	468 (12.2)	475 (11.8)	328 (12.0)	156 (16.7)	76 (18.0)
1985	700 (6.6)	799 (8.1)	964 (7.3)	461 (8.3)	92 (12.3)	58 (15.6)
1990	554 (11.2)	651 (21.7)	432 (17.1)	426 (13.9)	243 (26.1)	114 (26.2)
1995	927 (11.6)	830 (15.4)	427 (18.2)	740 (12.4)	576 (20.2)	196 (20.2)
Deer						
1988	468 (21.6)	262 (21.4)	350 (24.8)	286 (23.7)	101 (28.0)	40 (33.4)
1993	359 (15.5)	367 (24.4)	153 (22.7)	408 (16.7)	160 (44.7)	70 (45.1)

TABLE 6.—Fishing pressure, catch and harvest rates, and harvest of muskellunge estimated by creel survey in Bone Lake, Wisconsin, 1982 and 1985, and mean for eight Wisconsin lakes reported by Hanson (1986).

Lake and year	Fishing pressure (h/acre)	Catch rate (fish/100 h)	Harvest rate (fish/100 h)	Harvest (fish/acre)
Bone Lake				
1982	14.8	3.0	0.4	0.06
1985	18.7	3.4	0.6	0.11
Eight lakes[a]	15.3	1.4	0.9	0.20

[a] Reported by Hanson (1986).

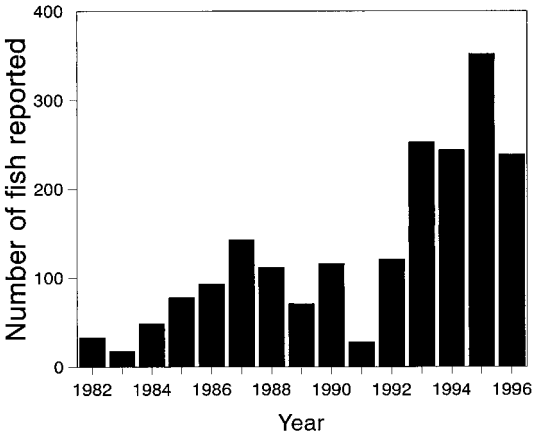

FIGURE 6.—Reported angler catch of muskellunge 30 in and longer from Bone Lake, Wisconsin, by members of Muskies, Inc.

high exploitation following the implementation of the 34-in length limit. The voluntary release rate from 1984 through 1986 averaged 44% ($N = 306$), and from 1987 through 1989 averaged 82% ($N = 389$). It's unknown whether the increased release rate was unique to Bone Lake following the length limit change or reflects increased awareness of the catch-and-release fishing ethic by anglers. In eight lakes sampled by Hanson (1986) from 1979 through 1982, voluntary release was estimated at 32%.

Muskellunge catch records from members of Muskies, Inc., also support the creel data that indicated increased fishing pressure and catch. Reported catch showed a steady increase in muskellunge 30 in and greater from 1983, the year of the length limit changed from 30 to 34 in, through 1987 (Figure 6). From 1988 through 1992, reported catch stabilized, with the exception of 1991, when catches were the lowest since 1983. Catch increased again in 1993–1996. Mean length of muskellunge caught was similar between periods 1982–1985 (mean = 34.9 in, SE = 0.34, $N = 100$) and 1985–1990 (mean = 35.1 in, SE = 0.15, $N = 497$) but increased during the period 1990–1996 (mean = 37.2 in, SE = 0.09, $N = 1,353$).

Discussion

Muskellunge mean length and population abundance probably increased from 1964 to 1982 because stocking shifted from fry and small fingerlings (≤5 in) to large fingerlings (≥9 in). Large fingerlings have higher poststocking survival (Hanson et al. 1986b; Margenau 1992) and, therefore, contribute more to the fishery. Sampling in 1965 indicated that 60% of adult muskellunge were age-4 fish, which were from a 1961 stocking that was more than twice the normal quota and was the highest number stocked up to that time. Increased stocking of large fingerlings through the 1960s and 1970s probably allowed the Bone Lake population to expand and shift toward older and larger fish.

The length limit increase from 30 to 34 in in 1983 caused increased angling pressure and harvest. As a result, the muskellunge population did not improve in terms of mean length, RSD, or abundance of larger fish from 1982 to 1985. Hanson (1986) found exploitation rate to be inversely related to population RSD. In Bone Lake, RSD-34 dropped 10%, and RSD-40 dropped 4% when exploitation rate increased from 10.4 to 36.0% from 1982 to 1985.

Reasons for the increase in fishing effort and harvest on Bone Lake may have been related to the uniqueness of the 34-in length limit. When the statewide length limit changed from 30 to 32 in in 1983, only 10 of 700 Wisconsin lakes implemented a 34-in length limit. Anglers may have interpreted the larger length limit as an opportunity to catch larger fish on these few waters. Margenau et al. (1994) found that the reputation or potential of a lake to produce large muskellunge was one of the main criteria used by anglers in selecting a lake to fish.

Following these initial responses, population abundance and mean length increased by 1990. Increases in population size structure, biomass, and mean length continued after implementation of the 40-in length limit in Bone Lake in 1990. The increase in numbers of larger (≥38-in) muskellunge was especially encouraging. A goal of minimum length limits is to increase angler yield or increase the number of large fish (Hanson 1986). Following the establishment of a 40-in minimum

length limit in Bone Lake, the number of muskellunge between 38 and 40 in increased nearly 300% and the number of fish 40 in and greater increased 72% by 1995. Abundance of muskellunge in Deer Lake remained similar from 1988 to 1993, and mean length increased, especially of male fish.

Minimum length limit changes had the greatest length effects on male muskellunge. From 1982 to 1995, male muskellunge mean length increased 3.3 in, while female muskellunge mean length increased 0.9 in. This may reflect the response of anglers to what is considered a socially acceptable length of muskellunge to harvest. Margenau et al. (1994) found that more than 98% of muskellunge anglers thought a muskellunge needed to be at least 40 in to be considered a trophy fish. Hence, harvest is probably targeted on larger female muskellunge. Interestingly, mean length changes in Deer Lake were also greater for male muskellunge. This happened in spite of the mean length change (33.2–34.5 in) being above the 32-in minimum length limit. In the absence of higher length limits, muskellunge anglers may self-impose a socially acceptable minimum length for harvest. Both of these scenarios contrast with changes during earlier periods (1964–1982), when the muskellunge population was expanding and mean length of female muskellunge increased more than mean length of male muskellunge.

Voluntary catch and release by anglers probably contributed to increased size structure and abundance in both Bone and Deer lakes. Catches reported at resorts on Bone Lake indicated a substantial increase in voluntary catch and release during the study. Because Bone and Deer lakes are only 13 mi apart, it is likely that muskellunge anglers on both lakes were similar and that voluntary release also increased on Deer Lake. Hence, voluntary release during this study was probably at least partly responsible for the increased muskellunge density in Bone Lake and improved length distributions in both Bone and Deer lakes.

Bone and Deer lakes both support high-density muskellunge populations. Density of muskellunge 30 in and greater was 0.99 fish/acre in Bone Lake in 1995 and 0.90 fish/acre in Deer Lake in 1993. Hanson (1986) reported a mean density of 0.33 fish/acre for muskellunge 30 in and greater (range, 0.09–0.61 fish/acre) for eight Wisconsin lakes. Similarly, biomass of adult muskellunge in Bone lake increased from 6.8 lb/acre in 1982 to 13.2 lb/acre in 1995. Hanson (1986) reported mean biomass of adult muskellunge in eight Wisconsin lakes at 3.6 lb/acre (range, 0–6.0 lb/acre).

A high abundance of top level predators may have subtle, but possibly detrimental, effects on aquatic communities. Declining condition (W_r) of muskellunge in Bone Lake during the study period suggests that appropriate forage fishes may have declined as the study progressed and muskellunge abundance increased. However, muskellunge were still robust at the end of the study (W_r = 96). Neumann and Willis (1994) reported mean W_r-values of 92.6 for 30–38-in muskellunge from 11 Wisconsin populations, of which only two populations had W_r-values of 96 or greater.

The decline in muskellunge condition with length in Bone Lake suggests intraspecific competition for food resources among larger fish. Porath and Peters (1997) concluded that changes in W_r of walleye by length-group was related to abundance of prey fishes available to each length-group. However, condition of larger fish in Bone Lake was comparable to that of muskellunge in other Wisconsin waters. Mean W_r for muskellunge 38 in and greater in Bone Lake (98.7) was similar to mean W_r (98.4) for muskellunge 38–42 in from 10 Wisconsin populations (Neumann and Willis 1994).

Muskellunge are not usually considered to have an effect on fish populations because they occur at low densities. However, artificially high densities can be achieved through stocking. Siler and Beyerle (1986) found that stocking fingerling muskellunge coupled with a 36-in minimum length limit in a 396-acre Michigan lake resulted in a density of adult muskellunge (≥30 in) of 0.84 fish/acre. Associated with the high muskellunge population was a decline in the populations of white sucker and black crappie. Hanson (1986) found that density of adult muskellunge had an inverse effect on male muskellunge growth and that catostomid density was positively related to muskellunge growth. In Bone Lake, more than 1,700 adult muskellunge (≥30 in) were present in 1995. With such artificially high densities, muskellunge may have effects on other fish species.

Managers should be cognizant of potential shifts in fish community structure from muskellunge stocking and establish a sampling program to monitor such long-term changes. Some changes in the fish community may be subtle, and considerable time can pass before the symptoms become obvious. However, such subtle changes in an aquatic community, once recognized, may take even longer to correct.

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