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INITIAL EFFECTS OF SLOT LENGTH LIMITS FOR NORTHERN PIKE IN FIVE NORTH-CENTRAL MINNESOTA LAKES[1]

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Abstract--High exploitation of large fish is a likely contributor to poor size structure in northern pike *Esox lucius* populations. Protected slot length limit regulations, which protect fish within a specified length range, are potential tools for managing size structure in northern pike populations. In this study, either 508-762 mm (20-30 inch) or 559-762 mm (22-30 inch) slot length limits were applied in five small north-central Minnesota lakes. The regulations were evaluated after three or four years at each lake. Angler non-compliance with the slot length limits was higher than expected, with tag returns from illegal fish averaging 19% of the total tag returns across the five lakes. Although there was considerable non-compliance, effects of the regulations were evident in size of fish measured in the creel surveys. Slot length limits directly reduced exploitation of large (>500 mm) northern pike, with the reductions being relatively large compared to pre-regulation exploitation rates and compared to exploitation rates in other reference lakes. After three to four years of regulation, however, the northern pike populations had not yet shown changes in size structure that were consistent across all lakes and sampling methods. The important remaining question from this study is whether or not slot length regulations will create long-term meaningful changes in sizes of northern pike. Only by monitoring effects of the regulations for a longer time will we be able to determine if natural mortality can overwhelm attempts to enhance numbers of large northern pike.

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Introduction

The northern pike *Esox lucius* is the most widespread game fish in Minnesota and provides many recreational fishing opportunities in the state's lakes and streams. Northern pike are present in all major drainages in Minnesota and have been found in about 80% of 3,900 lakes sampled by the Minnesota Department of Natural Resources. A common phenomenon in many of the lakes, especially in central and northern Minnesota, is large numbers of small northern pike and few fish of sizes preferred by anglers. Potential reasons for poor size structure include some combination of recruitment of large numbers of small northern pike (Kempinger and Carline 1978), a lack of prey fish of appropriate sizes (Snow 1978; Diana 1987), and lake characteristics such as the abundance of aquatic vegetation (Grimm 1981; Jacobson 1992) and presence of coolwater refuges for summer growth (Headrick and Carline 1993). Abundance of large northern pike may be particularly important in shaping the size structure of a population through cannibalism (Mann 1982).

In many of the lakes, excessive exploitation of large fish is likely to be one of the most important contributors to poor size structure in the northern pike populations. Weithman and Anderson (1978) and Beyerle (1978) have shown that northern pike can be highly vulnerable to angling. In Minnesota, regulations for recreational northern pike fishing have been used sparingly. Until this study, there had been no evaluated length limit restrictions and the bag limit was three northern pike. In May 1994, the statewide regulation was modified by the legislature to allow only one fish over 762 mm in the bag. With no strict length limits and historical increases in recreational fishing pressure, there has been a general decline in northern pike sizes. Analysis of northern pike entries in an annual fishing contest in northwestern Minnesota (1930-1987) showed a decline in the mean weight of entered fish from 4.6 kg in the 1930s to 3.1 kg in the 1980s (Olson and Cunningham 1989). Trophy entries of northern pike larger than 6.8 kg peaked in the late 1940s and have steadily declined since. Meanwhile, numbers of recreational anglers in Minnesota have more than tripled since the 1930s.

Among the most promising potential tools for managing size structure in fish populations are slot length limit regulations, which protect fish within a specified length range. Protective slot length limits were first described by Martin (1958) and Anderson (1976) as an approach to control exploitation and manage the size structure of largemouth bass *Micropterus salmoides* populations. In populations with high recruitment, a slot length limit allows fishermen to harvest small fish but protects quality-sized fish when they are exhibiting high absolute weight gains (Anderson and Weithman 1978). Stockpiling of fish within the slot may enhance opportunities for quality catch-and-release fishing as well as allowing anglers to creel more large animals that grow beyond the upper end of the protected slot. Eder (1984) found that a slot length limit was effective for managing a high density, slow growing largemouth bass population in Watkins Mill Lake, Missouri. The slot limit increased bass growth and numbers of quality-sized fish caught by anglers.

Because of poor or declining size structure in many northern pike populations, interest has heightened in providing recreational fisheries in Minnesota where anglers may be able to catch some larger northern pike. The purpose of this study was to evaluate the use of protective slot length limits for managing the size structure of northern pike populations. We applied experimental slot length limits to northern pike populations in five small north-central Minnesota lakes, then evaluated the regulations after they had been in effect for three to four years.

Methods

This study was conducted in eight small lakes distributed among three counties in north-central Minnesota (Table 1). The lakes ranged in size from 27 to 254 hectares with maximum depths ranging from 11 to 20 m. Percentages of the surface area shallower than 4.6 m ranged from 23 to 80%, and productivity and

Table 1. Lake location and basin characteristics for eight study lakes in north-central Minnesota. Littoral area was defined as the percentage of surface area shallower than 4.6 m.

	Lake							
Variable	Julia	Medicine	North Twin	French	Sissabagamah	Wilkins	Coon	Lake-of-Isles
County	Beltrami	Beltrami	Beltrami	Aitkin	Aitkin	Aitkin	Itasca	Itasca
Latitude	47°40'N	47°44'N	47°36'N	46°37'N	46°30'N	46°38'N	47°43'N	47°42'N
Longitude	94°53'W	94°44'W	94°36'W	93°33'W	93°36'W	93°30'W	93°34'W	93°34'W
Lake surface area (ha)	182	180	127	55	148	151	254	27
Littoral area (% surface)	38	69	42	45	60	28	80	23
Maximum depth (m)	13	13	20	11	11	12	11	15
Shoreline length (km)	8.7	6.8	5.8	4.3	5.6	3.9	14.5	4.8
Total alkalinity (mg/l as $CaCO_3$)	134	130	90	80	60	80	39	31

shoreline irregularity varied among the lakes. All of the lakes had private development such as houses and cabins along their shorelines except Coon-Sandwick (Coon) Lake and Lake-of-Isles, which were located in a state park. Lakes chosen for this study contained relatively high densities of northern pike, as measured from previous fish surveys conducted by the Minnesota Department of Natural Resources. Previous northern pike catch-per-unit-effort (CPUE) in standardized overnight gill net sets were 7 to 19 pike/net compared to a more typical statewide catch of 4 pike/net. Julia, Medicine and North Twin lakes were studied in 1988 and 1993, French, Sissabagamah and Wilkins lakes were studied in 1989 and 1994, and Coon lake and Lake-of-Isles were studied in 1990 and 1995.

Fish populations in each lake were studied using the following three approaches:

1) Tagging experiments were conducted to estimate exploitation rates. Northern pike were trapped and tagged during ice-out in the spring using 25.4 mm bar mesh trap nets with a single 12.2 m lead. Each fish was double marked with an individually numbered Floy[2] FD-68B tag and batch marked with a Dennison 08966 tag. Paddle-shaped ends were trimmed from Dennison tags to leave a single thin strand of plastic. Northern pike were only marked with numbered tags if they were able to maintain an upright position during handling. Fish unable to maintain an upright position were judged to be too stressed to include in the tagging study (Pierce and Tomcko 1993).

2) Relative abundance and fish sizes were characterized using test netting and electrofishing. Fish in each lake, except Lake-of-Isles, were sampled in late summer (31 July - 22 September) using multimesh experimental gill nets, trap nets, and by electrofishing. Efforts for the various gear types varied by lake size, and net locations were randomly picked from grid locations on maps of each lake. Nets were not set, however, at depths with dissolved oxygen levels below 3 mg/l. Between 6 and 12 overnight gill net sets, 10-20 overnight trap net sets, and 10-15 electrofishing transects were fished in each lake. Multifilament nylon gill

[2]Use of trade names does not imply endorsement of products.

nets were 76.2 m long and had panels with 19.1, 25.4, 31.8, 38.1, and 50.8 mm bar meshes. Trap nets had 19.1 mm bar mesh, 12.2 m leads, two throats, and a 0.9 x 1.8 m rectangular frame opening into the trap. The electrofishing boat was operated at 240 V and 5-7 A using pulsed direct current and a spherical anode. Night electrofishing transects were 10 min long parallel to the shoreline with two people netting the fish.

3) Creel surveys were conducted to determine angler use and harvest. A stratified creel survey was conducted from mid-May to mid-February following tagging on each lake except Lake-of-Isles. This period covered the entire open season for recreational northern pike fishing in Minnesota except that the surveys were not conducted in November as ice was forming on the lakes. Surveys included instantaneous angler counts and daylight angler interviews. A two-stage sampling scheme (Cochran 1977) was used to sample the creel. Stratification was by four seasons, and weekdays versus weekends and holidays. Completed trip interviews were obtained from anglers leaving the lakes, but some incomplete trip interviews were also obtained at the close of each sampling period. Catch rates (which included northern pike that were released) and harvest rates were calculated from angler interviews. Harvests of northern pike were estimated from the stratified creel by multiplying mean harvest rates by fishing effort for each season, then summing across the seasons. Weights of harvested fish that were not weighed by creel clerks were estimated using a length-weight regression developed from fish sampled by gill netting, trap netting, and electrofishing in each lake. Biomass of northern pike harvested in each lake was determined by multiplying the total number of northern pike harvested by the mean weight of harvested northern pike.

Rather than relying on voluntary tag returns to estimate annual exploitation rates, creel clerks monitored exploitation of tagged northern pike during survey periods. Our stratified sampling scheme was then used to estimate the total annual harvest of tagged fish from each lake. Estimates of variance for exploitation rates were not straightforward because the binomial mark-recapture experiment was combined with a stratified sampling scheme. The problem was treated as two-stage sampling with the mark-recapture experiment as stage 1 and the creel survey as stage 2. We made the assumption that the number of fish caught in each survey period was distributed as a Poisson random variable, so the variance estimate for exploitation was:

$$v(\hat{\mu}) = \frac{\mu}{M}\left(\frac{N}{n} - \mu\right)$$

where μ = annual exploitation rate; N = number of available creel survey periods; n = number of available creel survey periods that were sampled; and M = number of northern pike marked during spring sampling. The probability of a northern pike losing both tags was considered negligible (p=0.0003) and handling mortality for tagged northern pike was estimated to be 2.4% (Pierce and Tomcko 1993). Because no creel survey was conducted at Lake-of-Isles, tag returns from Lake-of-Isles were voluntary returns to a locked box at the lake.

Total length (TL) was measured for each northern pike, and proportional stock densities (PSD's) were calculated from length designations proposed by Anderson and Gutreuter (1983). Confidence limits for PSD's and other proportions were calculated using the quadratic formula described by Fleiss (1981).

Before we began any of the field studies, a simple yield-per-recruit model (Thompson and Bell model as described by Ricker 1975) was used to estimate appropriate size ranges for the slot length limits. Slot length regulations protecting northern pike between 559 and 762 mm total length were enacted at Medicine and North Twin lakes beginning in May 1989. Slot length regulations protecting 508 to 762 mm northern pike were enacted at Coon, Sissabagamah, and Wilkins lakes in May 1991. The length regulations were coupled with a bag limit of six fish, but only one fish over 762 mm was allowed in the bag. For the first year of sampling on each of these lakes, regulations were consistent with historical statewide regulations for northern pike.

French, Julia, and Lake-of-Isles were used as reference lakes for experimental control with the statewide regulations applicable to these lakes throughout the study. In Lake-of-Isles spring tagging and collection of tag returns from anglers were the only sampling. Therefore, Lake-of-Isles was only used for comparisons involving spring trapping and exploitation rates.

This study consisted of three treatments. The treatments were: 1) 559-762 mm slot length limits at Medicine and North Twin lakes; 2) 508-762 mm slot length limits at Coon, Sissabagamah, and Wilkins lakes; and 3) experimental references at French and Julia (and Lake-of-Isles for some parameters). Treatments were compared statistically using a nonparametric single factor analysis of variance (Kruskal-Wallis test; Zar 1984). Values used in the comparisons were differences between pre- and post-regulation fisheries parameters. For some parameters, where no difference was found between the two slot length limit treatments, the slot length regulation lakes were pooled for comparison with the reference lakes. Such two sample comparisons were made using the nonparametric Mann-Whitney test (Zar 1984).

Non-compliance with experimental slot length regulations was measured using three independent techniques. We monitored tag returns of illegal fish, numbers of illegal fish measured by creel survey clerks, and violations of the regulations reported by state conservation officers.

Results

Pre-regulation Conditions

Pre-regulation conditions in the seven most intensively studied lakes were documented by Pierce et al. (1995). Briefly, they found several differences in northern pike fisheries among the lakes. Medicine, North Twin, Sissabagamah, and Coon lakes were characterized by small size northern pike and the fishery by high angling catch rates. In contrast, Julia, French, and Wilkins lakes had larger northern pike and lower catch rates. Fishing effort during the open water season ranged from 38.3 to 91.3 angler-hr/ha among the lakes and was 0.6 to 15.2 angler-hr/ha during the ice fishing season (Table 2). Spearing for northern pike constituted 7 - 32% of the winter interviews at each lake.

Pierce et al. (1995) also found that northern pike harvest before the regulations ranged from 1.8 to 8.8 northern pike/ha (1.8-5.2 kg/ha; Table 2) with most of the harvest occurring during the summer. Typical angling catch rates were about one northern pike for every five hours of effort, and anglers released an average of 75% of the northern pike they caught. Annual exploitation rates based on tag returns ranged from 0.04 to 0.22 among the lakes (Table 3). The size-selective nature of the recreational fishery was evident in annual exploitation rates. Annual exploitation rates for the larger northern pike (>500 mm TL) were approximately 2 to 9 times greater than for smaller fish (±500 mm TL). Relatively high total annual mortality (mean = 0.48; Pierce et al. 1995) compared to annual exploitation rates (mean=0.09) indicated that natural mortality was an important aspect of northern pike population dynamics and may be particularly important for smaller pike.

Post-regulation Changes in the Northern Pike Populations

Slot length regulations affected exploitation rates for northern pike by directly reducing exploitation of large (>500 mm TL) northern pike. For individual lakes, the slot length regulations decreased annual exploitation rates of large northern pike by 3 - 23% (Table 3). Reductions in annual exploitation rates of >500 mm TL northern pike in regulation lakes were large compared to pre-regulation rates (average 12% decrease). Reference lakes averaged a 4% increase over the same period (Rank Sum Test P=0.02 for differences between reference and experimental lakes). In Medicine and North Twin lakes, the average reduction in exploitation rates for large northern pike was 9% compared to 14% in Sissabagamah, Wilkins, and Coon lakes. No significant difference was

Table 2. Estimates of fishing effort, angling catch rates, total harvest, and average length of harvested northern pike from creel surveys on seven of the study lakes. The percentage of northern pike anglers was the proportion of all anglers interviewed who said they were specifically fishing for northern pike; the percentage of spearers was the proportion of winter fishers who were spearing for northern pike; and the percentage of northern pike released was the proportion of northern pike that were caught and released by anglers as determined from interviews. Catch rates (including released fish) were calculated from data from all interviewed anglers and also those fishing specifically for northern pike.

	Reference lakes				559-762 mm slot limit				508-762 mm slot limit					
	Julia		French		Medicine		North Twin		Sissabagamah		Wilkins		Coon	
Variable	1988-89	1993-94	1989-90	1994-95	1988-89	1993-94	1988-89	1993-94	1989-90	1994-95	1989-90	1994-95	1990-91	1995-96
Fishing effort (angler-hr/ha)														
Open water season	38.3	49.4	65.1	58.9	79.2	69.8	53.3	53.7	73.2	57.0	49.8	78.0	91.3	61.2
Winter season	2.3	7.2	14.9	16.2	0.6	1.6	0.3	1.4	15.2	10.3	3.9	6.0	2.4	2.3
Total annual	40.6	56.6	80.0	75.1	79.8	71.4	53.6	55.1	88.4	67.3	53.7	84.0	93.7	63.5
SE	3.4	4.2	7.6	6.1	5.0	4.7	4.1	4.7	7.5	4.3	4.4	6.0	5.3	3.7
Northern pike fishing percentages														
Pike anglers (%)	26	13	18	24	17	25	13	18	17	17	30	29	23	13
Pike spearers (%)	16	25	32	18	25	11	29	0	7	0	28	0	15	1
Catch rate (fish/angler-hr) and percentage releases of northern pike														
All anglers														
Early summer	0.17	0.17	0.14	0.17	0.42	0.16	0.37	0.21	0.32	0.27	0.10	0.27	0.28	0.17
Late summer	0.13	0.11	0.15	0.91	0.33	0.25	0.27	0.36	0.13	0.26	0.11	0.34	0.15	0.16
Fall	0.05	0.44	0.01	0.48	0.43	0.43	0.63	0.18	0.10	0.84	0.06	0.18	0.21	0.08
Winter	0.15	0.51	0.14	0.14	0.07	0.10	0.33	0.11	0.16	0.12	0.14	0.23	0.05	0.10
Pike anglers														
Open water angling	0.33	0.23	0.32	1.63	0.91	0.49	0.82	0.35	0.53	0.61	0.23	0.63	0.49	0.50
SE	0.07	0.06	0.09	0.90	0.15	0.06	0.31	0.11	0.09	0.14	0.06	0.13	0.07	0.07
% of pike released	42	65	68	78	69	59	87	85	75	71	68	78	84	89
Total northern pike harvest														
Number/ha	3.1	3.5	3.5	4.2	8.8	6.3	2.2	1.4	4.2	6.2	1.8	6.6	2.4	1.0
Kg/ha	3.4	3.8	2.7	5.1	5.2	4.5	3.5	1.5	2.4	3.4	1.8	5.1	2.2	0.7
Size of creeled northern pike														
Mean length (mm)	555	561	485	568	469	496	542	541	476	460	533	493	547	479
SE	8	8	18	19	4	4	14	18	6	4	15	14	8	20

Table 3. Annual exploitation rates from tagging experiments and catch-per-unit-of effort, mean length, and PSD of northern pike from late summer gill netting and spring trap netting in north-central Minnesota study lakes.

	Reference lakes						559-762 mm slot limit				508-762 mm slot limit					
	Julia		French		Lake-of-Isles		Medicine		North Twin		Sissabagamah		Wilkins		Coon	
Variable	1988	1993	1989	1994	1990	1995	1988	1993	1988	1993	1989	1994	1989	1994	1990	1995
Annual exploitation rates																
All pike sizes	0.22	0.23	0.07	0.12	0.02	0.07	0.16	0.27	0.04	0.05	0.09	0.07	0.05	0.03	0.10	0.04
SE	0.04	0.05	0.02	0.04	-	-	0.03	0.05	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01
Pike ≤500 mm	0.15	0.15	0.05	0.04	0.00	0.03	0.13	0.23	0.02	0.04	0.07	0.08	0.03	0.06	0.03	0.05
Pike >500 mm	0.27	0.26	0.10	0.17	0.11	0.16	0.46	0.32	0.10	0.07	0.20	0.06	0.08	0.02	0.26	0.03
Gill net catch																
Mean number per net	5.9	7.7	2.7	6.5	-	-	8.4	9.5	6.3	9.0	6.1	5.4	4.6	6.3	5.2	8.0
SE	1.1	1.0	1.3	1.4	-	-	2.8	0.8	1.2	1.1	1.2	0.7	0.9	1.1	1.1	1.4
Mean length (mm)	551	556	511	433	-	-	467	532	469	565	429	451	492	481	481	456
SE	13	11	10	15	-	-	11	12	19	16	9	18	12	14	15	15
PSD	49	58	31	26	-	-	18	36	45	60	2	21	17	34	32	32
95% CL	35-63	45-70	12-59	14-42	-	-	10-30	25-48	30-61	48-71	0-14	10-38	8-33	21-49	21-46	22-44
Trap net catch																
Mean length (mm)																
Males	482	505	472	482	439	433	415	458	414	410	423	426	491	497	429	421
SE	5	6	3	6	4	8	3	4	6	11	2	3	3	6	4	7
Females	526	552	514	596	478	498	447	520	496	537	473	505	504	540	477	504
SE	4	6	3	7	11	7	4	8	7	13	5	8	5	8	8	9
All fish	502	528	488	486	455	471	419	457	452	484	433	457	496	501	461	477
SE	3	5	2	6	5	5	2	4	5	9	2	4	3	4	4	5
PSD	37	50	21	56	9	17	5	26	26	45	7	15	28	48	23	37
95% CL	33-41	45-55	19-24	52-61	6-14	12-25	4-7	23-30	22-31	38-52	5-8	13-19	24-31	44-52	20-27	33-41
% females of fish in the protected slot size ranges	74	64	64	54	33	75	93	89	75	77	49	75	39	36	49	73

found between the two types of regulations (Rank Sum Test P=0.56).

In contrast, exploitation rates for small northern pike (±500 mm TL) appeared to increase in lakes with the slot length limit and increased bag regulations. Increases for individual lakes ranged from 1% to 10% (Table 3). The increases were not, however, significant with respect to the reference lakes (Kruskal Wallis Test P=0.37).

Slot length regulations did not have a meaningful influence on relative abundance of northern pike. Gill net CPUE increased an average of 1.5 fish per net lift in slot length limit lakes. The increase was not significant when compared to control lakes where the average change was an increase of 2.8 fish per net lift (Kruskal Wallis test P=0.57). The largest increases were found in Coon, French, North Twin, and Wilkins lakes (Table 3).

Gill net catch showed some changes in northern pike sizes that were consistent with slot length limits, but recruitment of young northern pike also influenced the size observed in the gill net catch. The largest increase in PSD were observed in lakes with slot length limits (Table 3). PSD in four of the five slot limit lakes increased by 15% or more with an average increase of 14% among all of the slot limit lakes. Changes in gill net PSDs in the reference lakes were lower (Rank Sum Test P=0.10), averaging 2%. The most substantial increases in individual lengths of northern pike in the gill nets also occurred in slot length limit lakes (Figure 1). Increases in average length in Medicine and North Twin lakes were 65 mm and 96 mm, respectively. Decrease in mean lengths in Wilkins and Coon lake, as well as in the reference lake, French Lake, resulted from strong year classes of small northern pike caught during 1994-1995 (Figure 1). Larger numbers of 251-350 mm northern pike (1993 year class) were sampled in Wilkins Lake in 1994 than 1989. Similarly, in French Lake, the 1993 year class of northern pike (301-450 mm) was apparent in the 1994 gill net catches. During netting in Coon Lake in 1995, the 1993 and 1994 year classes (301-400 mm total length) were a large segment of the catch.

Changes in northern pike sizes encountered during spring trapping were not consistent with changes expected from the regulations. No consistent change in mean length of males was encountered in spring trapping among the lakes (Table 3), and the reference lakes were not significantly different than slot limit lakes (Kruskal Wallis Test P=0.57). The largest change in mean length of males was the increase observed in Medicine Lake. Female northern pike caught during spring trapping showed increases in mean length in all lakes, including the reference lakes. Furthermore, PSD of fish caught during spring trapping also increased in all lakes (Table 3). The large increase in mean length of females in French Lake, and a corresponding increase in PSD, had a large influence on statistical tests not showing significant differences between slot limit and reference lakes (Kruskal-Wallis Tests; P=0.41 for female mean length and P=0.61 for PSD).

Sex ratios of northern pike within protected size ranges did not change under the slot length regulations. For spring trap netting in the experimental lakes, females were, on average, 61% of the sample within the proposed protected size ranges before the regulations were enacted and 70% after the regulations were in effect, a 9% increase (Table 3). Proportions of females of similar sizes in the reference lakes also increased an average of 7% during the study, so that no difference was apparent between reference and slot limit lakes in the proportion of females protected by the regulations (Kruskal-Wallis Test P=0.57).

Changes in growth rates for both sexes of northern pike were variable among the lakes and showed no trend related to the slot length regulations. Growth rates from post-regulation samples were slower than pre-regulation samples in Coon and North Twin lakes (Table 4). In contrast, growth rates of males increased in Wilkins Lake and were somewhat faster for all fish older than age 2 in Lake Sissabagamah. The most dramatic increases in growth rate occurred in a reference lake, French Lake. Northern pike from Sissabagamah, Coon, and North Twin lakes had growth rates that were slowest among the study populations. Across

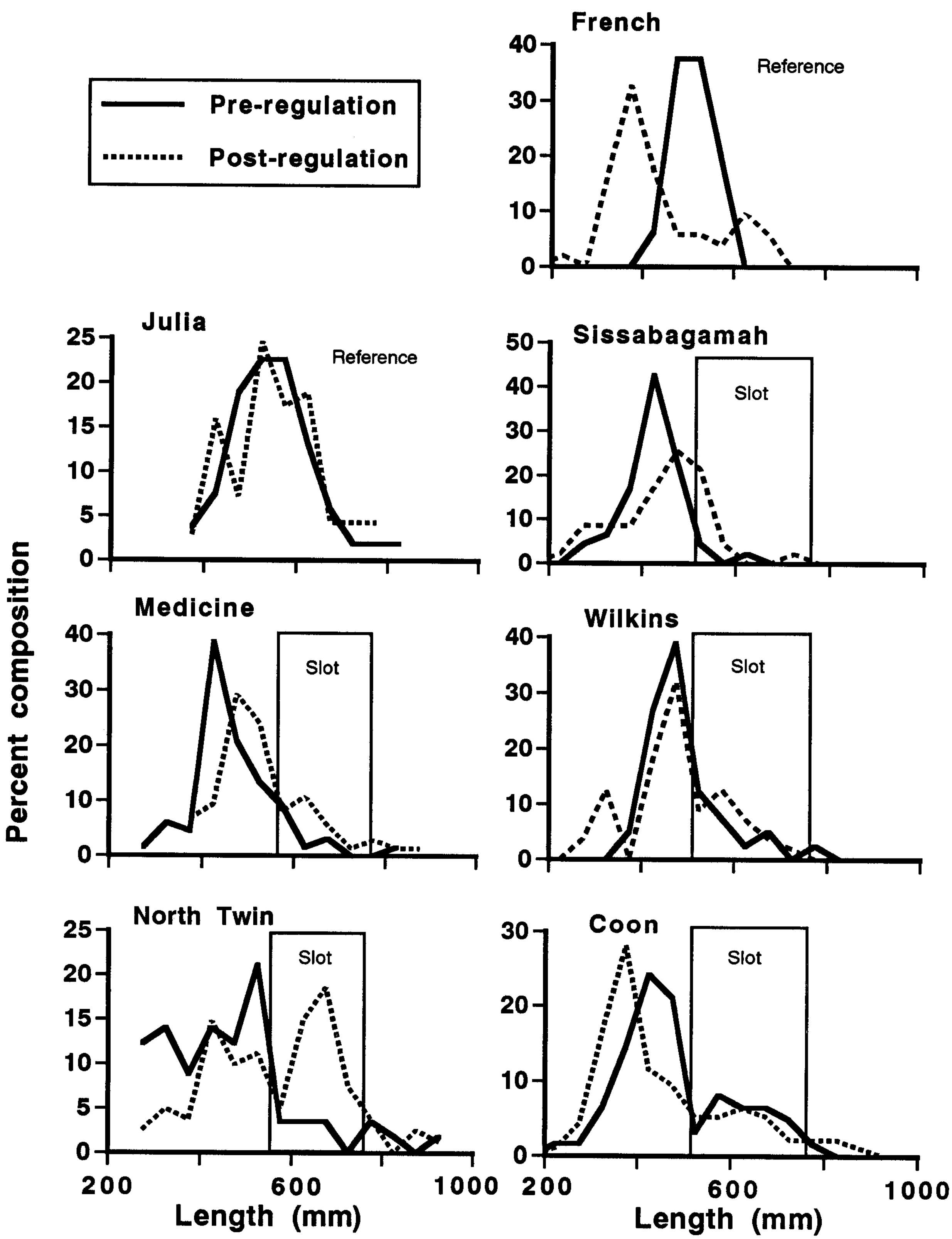

Figure 1. Length composition of northern pike sampled by gill netting.

Table 4. Mean back-calculated lengths, standard errors (SE) for back-calculated lengths, and sample sizes for northern pike caught during all late summer netting in Lake Julia, 1988 and 1993.

Age	Mean back-calculated length in mm (and SE)							
	All fish							
	1988		1993		Males 1993		Females 1993	
1	265	(6)	275	(7)	286	(14)	268	(9)
2	437	(7)	424	(8)	414	(15)	432	(11)
3	522	(11)	506	(9)	487	(14)	517	(11)
4	576	(17)	557	(14)	540	(25)	570	(18)
5	642	(27)	544	(15)			544	(15)
6	725	(36)	600	(1)			600	(1)
7								
n=	95		80		25		38	

Mean back-calculated lengths, standard errors (SE) for back-calculated lengths, and sample sizes for northern pike caught during late summer netting in Medicine Lake, 1988 and 1993.

Age	Mean back-calculated length in mm (and SE)											
	All fish				Males				Females			
	1988		1993		1988		1993		1988		1993	
1	222	(3)	237	(6)	214	(5)	220	(6)	235	(6)	255	(10)
2	383	(4)	416	(6)	365	(6)	396	(7)	402	(8)	436	(10)
3	479	(11)	495	(10)	433	(14)	455	(11)	506	(14)	533	(12)
4	568	(31)	540	(15)	505		491	(23)	578	(34)	577	(16)
5	661	(46)	593	(22)			533	(48)	661	(46)	631	(17)
6	723	(102)	684	(34)			770		723	(102)	702	(20)
7	656		755	(16)			790		656		746	(17)
8			798	(19)			817				779	
9			815	(22)			837				793	
10			825	(24)			849				801	
11			861				861					
n=	95		83		31		34		33		34	

Mean back-calculated lengths, standard errors (SE) for back-calculated lengths, and sample sizes for northern pike caught during late summer netting in North Twin Lake, 1988 and 1993.

Age	Mean back-calculated length in mm (and SE)											
	All fish				Males				Females			
	1988		1993		1988		1993		1988		1993	
1	190	(4)	188	(5)	189	(11)	168	(5)	234	(7)	202	(7)
2	332	(6)	328	(5)	317	(17)	300	(6)	400	(8)	345	(7)
3	440	(7)	439	(7)	431	(24)	398	(7)	505	(8)	459	(8)
4	512	(12)	514	(9)	497	(35)	453	(9)	576	(11)	538	(9)
5	587	(19)	579	(11)	618	(81)	505	(12)	627	(15)	601	(12)
6	652	(27)	632	(14)	716	(129)	547	(15)	678	(24)	641	(15)
7	737	(43)	668	(27)	740	(136)	561		733	(4)	680	(30)
8	815		697	(37)	895		588		775	(5)	713	(39)
9			714	(59)			620		790	(12)	746	(70)
10			747						805	(17)	747	
n=	85		85		16		27		29		46	

Table 4 Continued. Mean back-calculated lengths, standard errors (SE) for back-calculated lengths, and sample sizes for northern pike caught during late summer netting in French Lake, 1989 and 1994.

	Mean back-calculated length in mm (and SE)											
	All fish				Males				Females			
Age	1989		1994		1989		1994		1989		1994	
1	223	(5)	241	(4)	192	(11)	241	(10)	22	(13)	257	(6)
2	371	(7)	446	(12)	335	(21)	430	(23)	380	(18)	464	(17)
3	449	(7)	535	(14)	407	(19)	493	(2)	466	(15)	554	(17)
4	489	(8)	574	(13)	455	(15)	546	(7)	494	(10)	593	(11)
5	535	(23)			480							
6	568	(62)			489							
n=	65		95		9		13		10		38	

Mean back-calculated lengths, standard errors (SE) for back-calculated lengths, and sample sizes for northern pike caught during late summer netting in Lake Sissabagamah, 1989 and 1994.

	Mean back-calculated length in mm (and SE)											
	All fish				Males				Females			
Age	1989		1994		1989		1994		1989		1994	
1	187	(3)	175	(4)	178	(8)	171	(7)	186	(5)	179	(6)
2	329	(4)	333	(7)	311	(9)	313	(8)	339	(10)	340	(8)
3	414	(4)	436	(7)	381	(6)	409	(10)	427	(11)	440	(10)
4	466	(7)	491	(13)	416	(9)	447	(14)	472	(18)	499	(19)
5	493	(12)	553	(28)	405		469	(17)	450	(2)	584	(43)
6	561	(25)	777	(94)					462		777	(94)
7	605	(17)	920								920	
8	640	(17)	941								941	
9											956	
n=	150		66		23		14		24		29	

Mean back-calculated lengths, standard errors (SE) for back-calculated lengths, and sample sizes for northern pike caught during late summer netting in Wilkins Lake, 1989 and 1994.

	Mean back-calculated length in mm (and SE)											
	All fish				Males				Females			
Age	1989		1994		1989		1994		1989		1994	
1	194	(4)	207	(4)	179	(7)	213	(6)	209	(11)	206	(5)
2	368	(6)	401	(5)	341	(8)	403	(9)	392	(13)	397	(7)
3	455	(8)	500	(6)	420	(11)	502	(13)	497	(11)	501	(9)
4	514	(13)	551	(8)	479	(42)	556	(4)	543	(22)	553	(16)
5	554	(24)	614	(17)	558	(74)	599		583		642	(25)
6	616	(37)	616	(3)	736		618					
7	697	(76)			765							
8	570											
n=	84		78		26		14		15		39	

Table 4 Continued. Mean back-calculated lengths, standard errors (SE) for back-calculated lengths, and sample sizes for northern pike caught during late summer netting in Coon Lake, 1990 and 1995.

	Mean back-calculated length in mm (and SE)					
	All fish		Males		Females	
Age	1990	1995	1990	1995	1990	1995
1	193 (4)	182 (4)	203 (10)	171 (6)	193 (6)	186 (6)
2	327 (5)	308 (6)	314 (9)	293 (9)	342 (7)	313 (8)
3	433 (8)	403 (8)	400 (12)	374 (9)	453 (10)	414 (11)
4	529 (9)	485 (13)	479 (17)	423 (16)	549 (10)	508 (15)
5	597 (12)	573 (16)	571 (51)	506 (7)	601 (16)	579 (17)
6	648 (24)	632 (24)	613 (73)	568	651 (35)	635 (27)
7	689 (25)	655 (46)	706	606	679 (41)	696 (70)
8		724 (50)		627		756 (55)
9		679 (46)		633		725
n=	107	105	23	37	46	60

all of the lakes, males typically needed between three and six years, and females needed between two and five years to reach 508 mm (20 inches) total length.

Post-regulation Changes in the Recreational Fishery

Changes in fishing effort at each lake were attributed to local conditions, not to the experimental slot length regulations. Both increases and decreases in annual fishing effort were observed in the experimental lakes (Table 2), and changes in fishing effort were not directly related to the slot length regulations (Kruskal-Wallis Test $P=0.70$). The largest increase in annual fishing effort (30.3 angler-hr/ha) was found at Wilkins Lake, the only lake to have undergone substantial shoreline development during the study. The largest decrease in effort (30.2 angler-hr/ha) was at Coon Lake, in Scenic State Park, where Park attendance was 12% lower in 1995 than 1990.

Angling catch rates showed considerable seasonal as well as annual variability within each lake. In Lake Julia, for example, highest catch rates (including released fish) in 1988 occurred in early summer (Table 2). In 1993, the highest catch rates in Lake Julia occurred in winter. To compare pre- and post-regulation catch rates, we attempted to reduce some of the variability by using only catch rates for anglers who were specifically fishing for northern pike during the open water fishing season. The comparisons showed that differences between pre- and post-regulation measures of angler catch rates may have been affected by the years in which each lake was surveyed or by geographic differences among the lakes. The largest decreases in angling catch rates during the study were found in lakes sampled during 1988 and 1993. The largest increases in catch rates were found in lakes sampled during 1989 and 1994. Medicine and North Twin lakes, for example, showed large decreases in catch rates by northern pike anglers whereas French and Wilkins lakes had the largest increases in catch rates (Table 2).

Differences between pre- and post-regulation northern pike harvest also showed considerable variability among lakes (Table 2), but the variability was not related to slot length limits. Medicine, North Twin, and Coon lakes showed decreases in both numbers and weights of northern pike harvested. Sissabagamah and Wilkins lakes showed increases in numbers and weights of fish harvested. Reference lakes were intermediate between the two groups. Lake Julia showed only a modest increase in number and weight harvested. French Lake showed a modest increase in number harvested, but a relatively large increase in the weight harvested.

By reducing fish harvest in the protected size ranges, the regulations tended to reduce the average size of northern pike creeled. Slot length limits reduced the proportion of creeled fish in the protected size ranges by an average of 21%, with especially large reductions occurring in Wilkins and Coon lakes (Figure 2). Meanwhile, the proportion of creeled fish of the same sizes in reference lakes (559-762 mm in Julia and 508-762 mm in French Lake) increased by an average of 9%. The difference between reference and slot length limit lakes was significant (Rank Sum Test P=0.05), whereas no large difference was detected between the two types of slot length limits (Rank Sum Test P=0.20). In lakes with a 508-762 mm slot length limit, mean length in the creel was reduced between 17 and 68 mm (Table 3). However, no such reduction was found in Medicine Lake under the 559-762 mm slot length limit. The mean length of creeled fish actually increased by 26 mm in Medicine Lake as anglers harvested fish over 500 mm that were available in 1993. Before the regulation, catch in Medicine Lake was predominately 401-500 mm northern pike, whereas after the regulation the most numerous catch was 451-550 mm northern pike.

Experimental regulations did not seem to affect the proportion of anglers that were specifically fishing for northern pike, but did affect spear fishing. Proportions of creel survey interviews from anglers fishing for northern pike increased in Medicine and North Twin lakes (Chi-square test; P=0.00 and 0.08 respectively), but decreased in Coon Lake (P=0.00; Table 2). Changes in the proportions were not detected for Sissabagamah and Wilkins lakes. While slot length limits did not seem to influence proportions of northern pike anglers, the limits did deter spear fishers. Only three spear fishers were interviewed from slot limit lakes while the regulations were in effect (Table 2) compared to 48 interviews from pre-regulation surveys. For all slot limit lakes pooled, there was a significant decline in the proportion of winter interviews from spear fishers (Chi-square=25.77; df=1; P=0.00). No such difference was found for reference lakes (Chi-square = 0.35; df=1; P=0.56).

In both pre- and post-regulation creel surveys, anglers released a large proportion of the northern pike they caught. For each survey, between 42 - 89% of the catch was reported to have been released (Table 2). Unexplained was the fact that release rates did not seem to change in slot length limit lakes. The average change in release rates among slot limit lakes was 0% (range of -10% to 10%). The largest increase in the release rate for northern pike occurred in a reference lake (23% in Lake Julia).

Anglers did not take advantage of the expanded bag limit of six fish. The proportion of angling parties interviewed who kept more than three northern pike per person was very low. For all lakes with the six fish bag limit pooled, <1% of the parties kept more than three fish per person (5/612 interviews). On individual lakes, the proportion ranged from 0 - 3%. Interviews were only included if they were for completed trips and at least one northern pike was caught by the party.

Non-compliance with the slot size limits was higher than expected. During the years of the experimental regulations, creel clerks found that 6 - 19% of the fish they measured on each lake were illegal fish (average 13% across all slot limit lakes; Table 5 and Figure 2). Moreover, between 5% and 29% of tag returns were from illegal fish (average 19% across all slot limit lakes). In spite of the relatively high rates of non-compliance, conservation officers reported only two violations during the entire study period.

Although non-compliance was relatively high, exploitation of similar size fish in reference lakes was much greater (Table 5). In reference lakes, 47 - 66% (average 57%) of creeled fish and 54 - 85% (average 70%) of tag returns were fish of sizes that would have been protected by the slot length regulations.

Changes in the Fish Communities

Predominant in the fish communities were percids, centrarchids, small cyprinids, and ictalurids (Tables 6 and 7). White sucker *Catostomus commersoni*, bigmouth buffalo *Ictiobus cyprinellus*, bowfin *Amia calva*, darters *Etheostoma sp.*, banded killifish *Fundulus diaphanus*, and brook stickleback *Culaea inconstans*, were sampled in relatively low

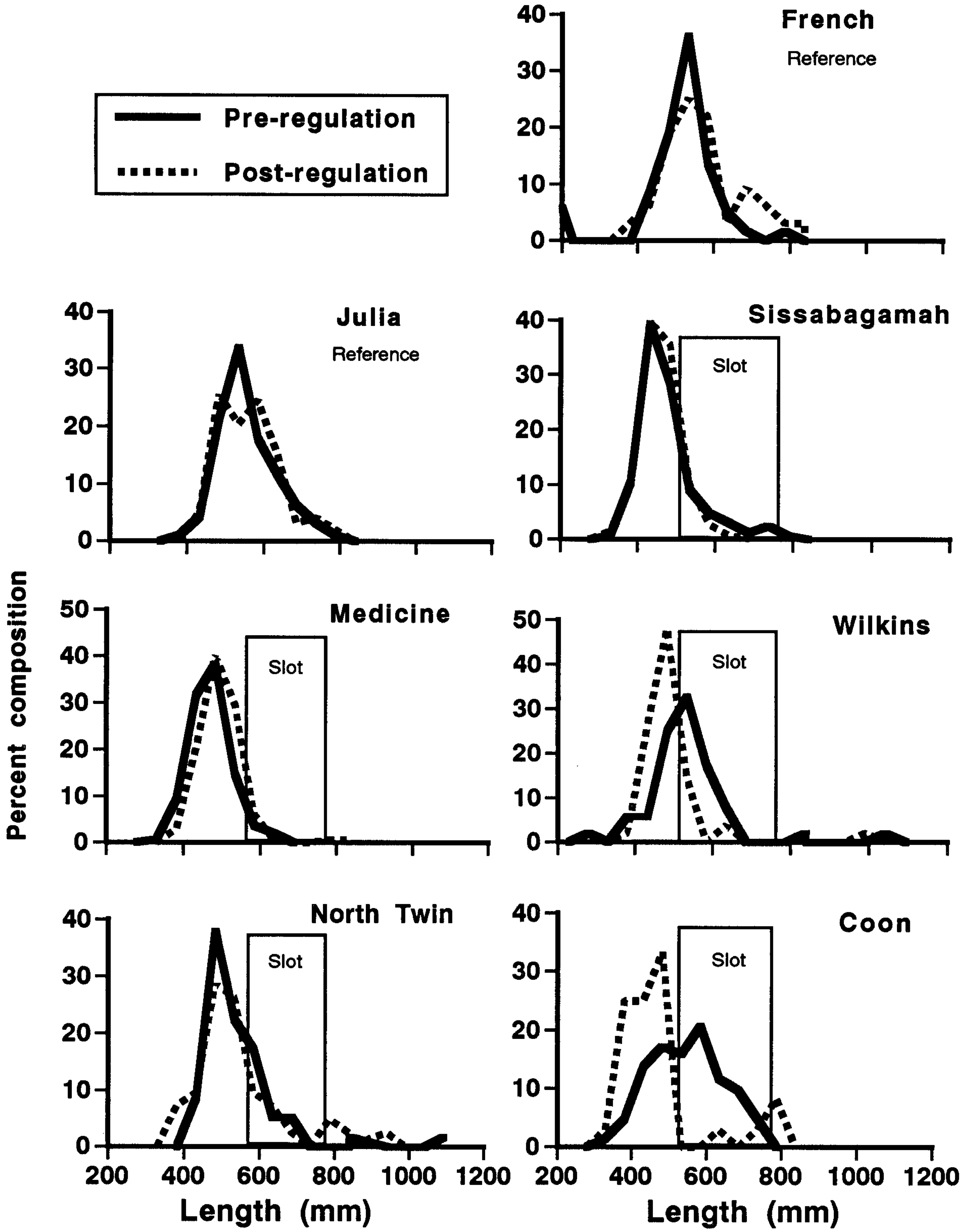

Figure 2. Length composition of northern pike sampled during creel surveys.

Table 5. Non-compliance with slot length limits as measured by percentages of illegal (slot-size) northern pike observed by creel clerks and tag returns from illegal fish. Reference lakes are also included for comparison, with northern pike slot lengths of 559-762 mm used for Lake Julia and 508-762 mm fish used for French Lake.

	1993-94			1994-95			1995-96
Variable	Julia	Medicine	N.Twin	French	Sissabagamah	Wilkins	Coon
% slot-size fish in creel	47	7	19	66	14	19	6
% tag returns from slot-size fish	54	5	14	85	21	29	27

Table 6. List of common and scientific names of fish found in seven of the north-central Minnesota study lakes. An "X" denotes presence of a species in a lake.

Common Name	Scientific Name	Julia	Medicine	North Twin	French	Sissa-bagamah	Wilkins	Coon
Bowfin	Amia calva				X	X	X	
Central mudminnow	Umbra limi	X	X	X	X	X	X	X
Northern pike	Esox lucius	X	X	X	X	X	X	X
Golden shiner	Notemigonus crysoleucas	X	X	X	X	X	X	X
Common shiner	Luxilus cornutus				X			
Blackchin shiner	Notropis heterodon	X	X	X	X	X	X	X
Blacknose shiner	Notropis heterolepis	X	X	X	X	X	X	X
Spottail shiner	Notropis hudsonius			X	X	X	X	X
Spotfin shiner	Notropis spilopterus		X		X			
Mimic shiner	Notropis volucellus	X		X	X		X	
Bluntnose minnow	Pimephales notatus	X	X	X	X	X	X	X
Fathead minnow	Pimephales promelas		X		X			X
White sucker	Catostomus commersoni	X	X	X	X	X	X	X
Bigmouth buffalo	Ictiobus cyprinellus						X	
Black bullhead	Ameiurus melas	X			X	X	X	X
Yellow bullhead	Ameiurus natalis				X	X	X	
Brown bullhead	Ameiurus nebulosus	X	X	X	X	X	X	X
Tadpole madtom	Noturus gyrinus	X	X	X	X		X	X
Burbot	Lota lota	X			X			
Banded killifish	Fundulus diaphanus	X	X	X			X	
Brook stickleback	Culaea inconstans	X	X	X	X			
Rock bass	Ambloplites rupestris	X	X	X	X	X	X	
Pumpkinseed	Lepomis gibbosus	X	X	X	X	X	X	X
Bluegill	Lepomis macrochirus		X	X	X	X	X	X
Smallmouth bass	Micropterus dolomieu			X				
Largemouth bass	Micropterus salmoides		X	X	X	x	X	X
Black crappie	Pomoxis nigromaculatus		X	X	X	X	X	X
Iowa darter	Etheostoma exile	X	X	X	X		X	X
Johnny darter	Etheostoma nigrum	X	X	X	X		X	X
Yellow perch	Perca flavescens	X	X	X	X	X	X	X
Walleye	Stizostedion vitreum	X	X	X	X	X	X	X
Freshwater drum	Aplodinotus gunniens		X					
Mottled sculpin	Cottus bairdi							X

Table 7. Catch-per-unit-effort for gill netting, trap netting, and electrofishing during late summer in Lake Julia.

	Gill net (#/net)		Trap net (#/net)		Electrofishing (#/10 min)	
	1988	1993	1988	1993	1988	1993
Central mudminnow						3.3
Northern pike	5.9	7.7	0.2	1.1	0.5	0.7
Cyprinids					13.7	9.2
White sucker	0.2	0.2			0.1	0.1
Black bullhead		3.0		0.3	13.6	0.4
Brown bullhead	66.0	3.9	1.0	0.7	3.5	1.3
Tadpole madtom					0.4	
Burbot		0.1				
Banded killifish					3.1	0.1
Brook stickleback						0.2
Rock bass	11.8	6.3	7.8	1.4	7.6	3.4
Pumpkinseed	3.9	0.6	3.4	0.2	2.5	0.7
Iowa darter					0.1	
Johnny darter						0.1
Yellow perch	119.0	116.3	3.9	1.5	52.9	40.2
Walleye	7.1	7.6	1.3	0.7	2.9	7.9

Catch-per-unit-effort for gill netting, trap netting, and electrofishing during late summer in Medicine Lake.

	Gill net (#/net)		Trap net (#/net)		Electrofishing (#/10 min)	
	1988	1993	1988	1993	1988	1993
Central mudminnow					0.9	4.2
Northern pike	8.4	9.5	0.6	0.5	2.1	1.4
Cyprinids					18.4	8.3
White sucker	0.8		0.4	0.2	0.3	0.1
Brown bullhead	2.6	2.9	1.6	0.1	3.9	2.3
Tadpole madtom					0.4	0.1
Banded killifish					0.4	0.2
Brook stickleback						0.1
Rock bass	0.9	1.0	1.1	0.1	1.6	2.8
Pumpkinseed	12.1	6.5	5.8	0.9	2.7	2.6
Bluegill	0.6	0.6	1.6	0.5	17.6	7.1
Largemouth bass	1.0	1.0	1.2	0.3	1.7	1.8
Black crappie	1.8	4.0	0.1	0.1	2.3	2.4
Iowa darter					0.1	
Johnny darter						0.1
Yellow perch	3.3	17.3	0.5	0.2	19.3	43.7
Walleye	3.5	1.9	0.1	0.4	0.1	0.5
Freshwater drum		0.1				

Table 7 Continued. Catch-per-unit-effort for gill netting, trap netting, and electrofishing during late summer in North Twin Lake.

	Gill net (#/net)		Trap net (#/net)		Electrofishing (#/10 min)	
	1988	1993	1988	1993	1988	1993
Central mudminnow					0.9	2.0
Northern pike	6.3	9.0	0.8	1.0	1.7	0.9
Cyprinids					26.9	42.8
White sucker	0.1		0.1		0.2	
Brown bullhead	1.0	0.9			0.1	
Tadpole madtom					0.2	
Banded killifish					0.1	
Brook stickleback						0.1
Rock bass	2.3	7.4	0.4	0.4	6.8	8.2
Pumpkinseed	2.0	0.8	1.0	0.4	0.7	1.8
Bluegill	15.7	9.3	13.9	12.0	25.7	45.6
Smallmouth bass	0.1	0.1	0.1		1.3	0.1
Largemouth bass	2.7	2.1	0.3	0.9	0.8	2.6
Black crappie	0.3	0.1		1.3		0.7
Iowa darter						0.3
Johnny darter						0.3
Yellow perch	6.7	11.8	0.2		2.8	21.4
Walleye	3.4	1.8	0.2	0.2	0.8	0.1

Catch-per-unit-effort for gill netting, trap netting, and electrofishing during late summer in French Lake.

	Gill net (#/net)		Trap net (#/net)		Electrofishing (#/10 min)	
	1989	1994	1989	1994	1989	1994
Bowfin	0.3		1.0	1.1	0.6	0.2
Central mudminnow						2.0
Northern pike	2.7	6.5	0.6	0.7	2.5	4.5
Cyprinids					134.3	49.3
White sucker	0.7	1.4	0.1		1.3	1.3
Black bullhead	0.3					
Yellow bullhead	0.2	0.5	1.7	0.3	1.0	0.4
Brown bullhead	1.2	0.3	0.3	0.4	0.1	0.1
Tadpole madtom					1.7	0.3
Burbot		0.1				
Brook stickleback					0.7	0.3
Rock bass		0.1	0.1	0.9	6.0	1.1
Pumpkinseed			0.9	0.3	3.0	
Bluegill	1.0		8.9	7.6	125.0	124.0
Largemouth bass				0.2	1.2	1.0
Black crappie	6.7	8.4	2.8	5.1	8.7	28.0
Iowa darter						0.3
Johnny darter					1.3	
Yellow perch	0.8	8.3	0.1	1.9	468.7	425.0
Walleye	1.2	2.8	0.2	0.1	0.6	0.3

Table 7 Continued. Catch-per-unit-effort for gill netting, trap netting, and electrofishing during late summer in Lake Sissabagamah.

	Gill net (#/net)		Trap net (#/net)		Electrofishing (#/10 min)	
	1989	1994	1989	1994	1989	1994
Bowfin	0.2	0.3	1.3	0.4		0.1
Central mudminnow						0.8
Northern pike	6.1	5.4	1.0	1.2	2.9	1.3
Cyprinids					76.3	19.4
White sucker	0.4	0.1				
Black bullhead	0.4	0.1				
Yellow bullhead	15.9	10.3	2.9	3.3	1.8	0.6
Brown bullhead	1.9	1.7	0.1	0.5		0.1
Rock bass	0.3		0.3	0.2	0.3	1.0
Pumpkinseed	2.1	1.2	4.4	0.6	3.3	5.2
Bluegill	3.1	6.4	9.6	7.4	78.0	35.0
Largemouth bass	0.4	0.9	0.2	0.3	0.7	1.8
Black crappie	6.6	3.0	1.2	0.3	7.0	1.8
Yellow perch	0.1	0.4	0.4		63.0	14.0
Walleye	2.3	1.6				

Catch-per-unit-effort for gill netting, trap netting, and electrofishing during late summer in Wilkins Lake.

	Gill net (#/net)		Trap net (#/net)		Electrofishing (#/10 min)	
	1989	1994	1989	1994	1989	1994
Bowfin		0.1	0.1	0.3	0.1	
Central mudminnow					0.1	
Northern pike	4.6	6.3	0.6	0.9	0.5	1.3
Cyprinids					47.7	145.3
White sucker						0.1
Bigmouth buffalo				0.3	0.1	
Black bullhead	0.3		0.1			
Yellow bullhead	6.8	5.7	3.8	1.6	1.8	0.4
Brown bullhead	1.4	1.1	0.2	1.0	0.1	
Tadpole madtom						0.3
Banded killifish						0.8
Rock bass	2.7	1.6	0.3	0.5	1.7	3.0
Pumpkinseed	0.8	0.4	4.7	1.3	1.7	0.3
Bluegill	3.0	7.2	37.1	32.0	115.3	87.5
Largemouth bass	2.0	3.9	1.7	0.4	2.7	1.9
Black crappie	4.3	3.0	3.3	2.3	2.3	2.8
Iowa darter						0.3
Johnny darter						1.0
Yellow perch	0.1	2.0	0.3	0.8	91.3	226.5
Walleye	6.1	5.6	0.2	0.3		0.5

Table 7 Continued. Catch-per-unit-effort for gill netting, trap netting, and electrofishing during late summer in Coon Lake.

	Gill net (#/net)		Trap net (#/net)		Electrofishing (#/10 min)	
	1990	1995	1990	1995	1990	1995
Central mudminnow					1.5	0.8
Northern pike	5.2	8.0	0.8	0.7	2.0	0.6
Cyprinids				0.1	15.8	75.2
White sucker		0.1			0.1	
Black bullhead	8.6	4.9		0.1		0.2
Brown bullhead	11.8	18.1	0.1	0.3	1.4	0.9
Tadpole madtom					0.2	0.1
Pumpkinseed	1.8	1.8	2.6	0.8	1.1	3.8
Bluegill	8.8	11.5	8.9	5.5	49.9	121.9
Largemouth bass	0.6	0.3	0.4	0.7	2.1	5.8
Black crappie	1.3	0.5	1.3	0.6	5.7	8.3
Iowa darter					0.1	0.8
Johnny darter					0.3	0.1
Yellow perch	6.7	12.4	0.1	0.4	8.0	77.0
Walleye	1.2	0.7	0.1	0.1	0.5	0.1
Motted sculpin					0.1	

numbers. Lake Julia was somewhat unique among the study lakes in having no bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, or black crappie *Pomoxis nigromaculatus*. Also unique were the abundance of smallmouth bass *Micropterus dolomieu* in North Twin Lake and absence of rock bass in Coon Lake. Burbot *Lota lota*, freshwater drum *Aplodinotus gunniens*, and mottled sculpin *Cottus bairdi* were only represented by single individuals in the catch. Diversity of fish in the catch from each lake ranged from 19 to 28 species.

In some instances, there were large changes in abundance or sizes of different fish species caught during pre- versus post-regulation sampling (Table 7). In Lake Julia, we found relatively large declines in catch of rock bass *Ambloplites rupestris* and brown and black bullhead *Ameiurus nebulosus* and *Ameiurus melas*. Intensive netting for bullhead occurred in Lake Julia after commercial fishing privileges were transferred to a different fisherman in 1993. He removed over 3,600 kg of bullhead in May 1993. In Coon lake, much larger numbers of small bluegill were found in 1995 than 1990. Average CPUE for bluegill in Coon Lake was 49.9 fish/10 min (SE=6.4) electrofishing in 1990 compared to 121.9 fish/10 min (SE=25.5) in 1995. Average length of the electrofished bluegill in Coon Lake was 115 mm (SE=4) in 1990 versus 50 mm (SE=2) in 1995.

Differences between pre- and post-regulation samples were more commonly found for yellow perch *Perca flavescens* populations. Greater numbers of small yellow perch were seen during post-regulation electrofishing in Medicine, North Twin, Wilkins, and Coon lakes (Table 7). Average length of the yellow perch shocked in those lakes ranged from 58 to 90 mm during post-regulation sampling. Medicine Lake provided the only example where increased relative abundance was found for both large and small yellow perch. Increased abundance of large yellow perch was evident in gill net catch where the mean length of yellow perch gill netted in 1993 was 163 mm. CPUE increased for both gill netting and electrofishing in Medicine Lake. In contrast to the other four slot limit lakes, numbers of small yellow perch sampled by electrofishing in Lake Sissabagamah did not increase.

Because yellow perch are an important food item for northern pike, changes in pike populations might be expected to have effects on yellow perch populations. Yet, changes in sizes and catch rates of northern pike were not well correlated with changes in yellow perch sizes or catch rates. Significant linear associations ($P<0.05$; $df=5$; $r>0.75$) were not found between changes in northern pike CPUE, mean length, or PSD in gill nets and changes in yellow perch CPUE and mean length from gill netting or electrofishing (Table 8).

Discussion

The most readily apparent consequence of slot length limits was to reduce exploitation of slot-sized northern pike. The reductions in exploitation were large as a percentage of pre-regulation exploitation rates, and were also relatively large compared to exploitation in the reference lakes. Effects of the slot length limits were also evident in fish size measured in the creels. Even though there was some non-compliance with the regulations in slot limit lakes, harvest of slot-sized fish were much greater in reference lakes.

After three to four years of regulation, the northern pike populations had not yet shown any changes in size structure that were generally consistent across all of the lakes and sampling methods. Gill net catch provided the most encouraging sign that slot limits may ultimately improve fish sizes. We found increased PSDs from gill net catch in the slot limit lakes. PSD was a useful metric to consider because PSD is less sensitive to catches of very small fish than mean length. Spring trap netting results, on the other hand, were not consistent with the gill net catch because PSD and mean length increased in all lakes, including the reference lakes. In both reference lakes where we obtained spring trapping and late summer gill net samples, the increases in fish lengths observed in spring were not seen later in the summer after the fish had been exposed to fishing. Within an individual slot limit lake, the most consistent increases in northern pike size occurred in Medicine Lake, which also had the best record for compliance with the regulation. Most fishing pressure on the lake was from a resort where the regulation was actively promoted by the owner and his clients.

Previous studies have shown that northern pike population dynamics can respond to changes in exploitation. Increased harvests (primarily from netting) caused changes in growth rates or age and size structure of northern pike populations in Lake Windermere, England (Frost and Kipling 1967) and Lake Vastra sjo, Sweden (Otto 1979). Diana (1983) related differences in ages of first maturity of northern pike to differences in exploitation among three Michigan lakes. Minimum size limits protecting small northern pike have increased abundance of small fish and reduced growth rates. A 559 mm (22 inch) minimum size limit in Escanaba Lake, Wisconsin, caused increased biomass and decreased growth rates for northern pike (Kempinger and Carline 1978). On the other hand, Bucks Lake, Wisconsin, provided an example where a northern pike population did not respond to a minimum size limit. A 457 mm (18 inch) minimum size limit in Bucks Lake had no effect on growth

Table 8. Matrix of correlation coefficients (r) for northern pike and yellow perch catch in seven north-central Minnesota lakes. The number of degrees of freedom was 5 and P>0.05 for all correlations.

Variable	Northern pike gill net catches		
	Mean number/ net lift	Mean length	PSD
Yellow perch gill net catches			
Mean number per net lift	0.25	0.16	-0.09
Mean length	0.29	-0.10	-0.12
Yellow perch electrofishing catch			
Mean number per 10 min	0.14	0.04	0.19
Mean length	-0.17	-0.33	-0.13

(Snow and Beard 1972). The northern pike population in Bucks Lake was characterized by very slow growth of individuals and high total mortality rates (average 64% annually) compared to exploitation rates (average 9% annually). In effect, the minimum size limit in Bucks Lake only served to protect small, slow-growing fish that had a high rate of natural mortality.

Potential reasons that the northern pike populations in our slot limit lakes had not yet shown consistent changes in size structure, relative abundance, or growth rates include the short evaluation period, fluctuating year class strengths, and environmental variation. The evaluation period was not very long considering that a northern pike's life span can be 10 years or more, and that northern pike needed between two and six years to grow into the protected slot size range. Non-compliance would also serve to prolong the amount of time necessary to change the size structure of a population. Fluctuations in catch of small northern pike influenced measures such as mean length. For example, catch of yearling northern pike reduced mean length reported from spring trap nets in Wilkins Lake in 1994 compared to 1989. Adding yet another complicating factor, changes in northern pike size observed during trapping in French Lake may have been influenced by spring water levels. Relatively high water levels along with flowing water in inlets and outlets to French Lake in spring 1994 permitted greater movement of spawning northern pike to French Lake from connected water bodies.

Other potential reasons for seeing no consistent change in northern pike size in slot limit lakes would be loss of fish to hooking mortality, or compensatory natural mortality with slot-sized fish dying of natural causes even if they are left unharvested. Hooking mortality for northern pike has generally been reported as 5% or less for a variety of angling methods (Beukema 1970; Falk and Gilman 1975; Weithman and Anderson 1978; Schwalme and Mackay 1985; and DuBois et al. 1994). Falk and Gilman (1975) reported one case where mortality was 11% for fish caught and released with barbless hooks, but the sample size was small (2/19 fish). In the worst reported case of hooking mortality, DuBois et al. (1994) found 33% mortality for northern pike caught through the ice on Swedish hooks baited with smelt *Osmerus mordax*, a technique not used by anglers at our study lakes. The notion of compensatory natural mortality acting on slot-size fish runs contrary to the assumption made by Pierce et al. (1995) that natural mortality should be low for large northern pike. In Lake Windermere, the gill net fishery (which selected for fish >550 mm) caused increased total mortality, but there was no evidence that natural mortality significantly changed (LeCren 1987). Only by monitoring effects of the slot length regulations for a longer time will we be able to determine if natural sources of mortality can overwhelm our attempts to enhance numbers of large northern pike.

Year-to-year and seasonal variations in northern pike catchability, rather than the regulations, seemed to influence angling catch rates and harvests during the first three to four years of the slot length limits. In particular, the increases in numbers and weight of fish harvested in Sissabagamah and Wilkins lakes were not expected. We expected instead to see reductions in harvest such as those found in Medicine, North Twin, and Coon lakes with the additional protection afforded by slot length limits. Because of the method used to estimate harvest, our harvest estimates were closely tied to catch rates.

Except for winter spearing, the slot length limits did not seem to have any large effects on angling clientele or annual fishing efforts. No trend was observed in the proportion of interviews in which anglers said they were specifically fishing for northern pike and catch-and-release rates have remained high throughout the study. Nor were changes in annual fishing effort linked to the slot limits. The most affected clientele were spear fishers. They apparently avoided the slot limit lakes even though ice conditions were suitable for winter spearing, as evidenced from reference lakes.

Creel surveys in this study confirm that liberalized bag limits are not a useful tool for "thinning out" dense populations of small northern pike. Previous arguments against the liberalized bag limits included the fact that few fishing parties harvested daily limits of northern pike under the statewide bag limit of three fish (Goeman et al. 1993).

This study also showed that we face problems with angler non-compliance and enforcement of special regulations. Promotion of the regulations required extensive efforts, yet were apparently unsuccessful in reaching people and informing them about the regulations. Promotion efforts included publication of the regulations in annual fishing synopses, news releases, posting of red and white signs at public accesses, personal contacts with property owners and a lake association, distribution of adhesive rulers showing the slot size limit, and distribution of catch-and-release (barbless hook) lures attached to cards describing the regulations and tips for releasing fish. Location of Coon Lake within Scenic State Park afforded an even higher degree of control and visibilty. Promotion efforts in the park consisted of a printed flier given to anglers entering the park, personal contacts by park naturalists, and signs posted at campgrounds and picnic areas. In spite of these efforts, enough tags from slot-sized northern pike were recovered from fish cleaning houses at the park to show that some anglers ignored or were oblivious to the regulation. State conservation officers did not effectively enforce the regulations.

Management Implications

Results from this work demonstrate that we need to be fully committed to long-term studies for evaluating length limit regulations. Fish longevity and growth rates, fluctuating environmental conditions, and even angler non-compliance with regulations are all factors that can prolong the time necessary to adequately evaluate length limits. Because of the extensive amount of background data already collected for this study, we recommend extending the evaluation period on each lake for another 10 years. The big question is whether or not slot length regulations will ultimately result in meaningful changes in northern pike size available to anglers. If sizes are improved, then compensatory natural mortality is not an important factor.

Post-regulation creel surveys showed that the liberalized six fish bag limit was seldom used, and therefore had little chance of influencing the pike populations in this study. To simplify the regulations, we recommend that the expanded bag limits revert to the statewide bag limit.

One of the future visions for fisheries management in Minnesota is an increased reliance on individual lake management and special regulations. Levels of non-compliance in this study show that individual lake management is going to require a fishing public that is more aware of special management and receptive to special regulations. As evidenced in Medicine Lake, self promotion of the regulation among anglers was more effective than our efforts. The high level of compliance and the concurrent changes in fish sizes in Medicine Lake was encouraging, especially considering the poor initial population size structure found in Medicine Lake.

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