CHANGES IN POPULATION DENSITY, GROWTH, AND HARVEST OF NORTHERN PIKE IN ESCANABA LAKE

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ABSTRACT

The purpose of this study was to document changes in population density, growth, and harvest of northern pike (*Esox lucius*) in Escanaba Lake after implementation of a 22-inch size limit. The study covered a period of 5 years (1959-63) with no regulations and 9 years (1964-72) with a length limit.

Population densities of northern pike were estimated annually by mark-recapture methods. Growth rates and condition factors were estimated annually and total mortality rates were determined using catch curve techniques. A complete record of fishing pressure and harvest, obtained through a compulsory fishing permit system, allowed estimation of exploitation rates.

After the size limit went into effect in 1964, mean population density of northern pike increased by at least 92% and mean biomass increased by 43% (4.9 to 7.1 lb/acre). Most of this increase was due to pike under 22 inches; their densities increased by 99% while pike over 22 inches increased by 47%. Prior to 1964 total mortality rates were estimated at 60%; fishing mortality was 46% and natural mortality was 14%. Mean total mortality rates increased to 82% after implementation of the size limit; natural mortality increased to 76% and fishing mortality declined to 6%. Based on average mortality rates before and after 1964, it was estimated that recruitment had increased by about 160%.

Implementation of the size limit resulted in a marked reduction in harvest of northern pike. Mean numbers of harvested pike declined by 84% and total yield fell from 3.2 to 0.9 lb/acre. There was a decline in fishing pressure after 1964, but this did not appear related to the reduction in harvest. Numbers of pike over 22 inches in the harvest remained about the same, but their mean weights declined from 3.4 to 2.7 lb. The only fishery statistic that improved after 1964 was the mean catch rate of pike over 22 inches; it increased from 0.4 to 0.8 pike/100 hours.

After the size limit was implemented growth rates declined and age of maturity increased by about two years for both male and female pike. Mean lengths of Age 2 and 3 male pike declined by 19% and 20%, respectively, after 1964. Mean condition factors of adult pike declined steadily from 1959 to 1972, with the exception of two years, when there was an apparent temporary increase in forage species.

Panfish populations had been declining when the size limit was implemented. It is not known if reduction in fishing mortality on pike contributed to the continued panfish decline. However, it was hypothesized that initial development of the pike population around 1957 precipitated the decline of panfish and that reduced growth rates of pike were related to a diminishing food supply.

We used Ricker's (1975) equilibrium yield model to compute the maximum theoretical yield that could be obtained with a size limit providing growth rates, recruitment, and natural mortality remain constant. The maximum theoretical yield was 34% greater than that predicted with no size limit; however, observed yield with a size limit declined by 73%. The disparity between theoretical and observed yields was probably due to reduced growth rates.

CHANGES IN POPULATION DENSITY, GROWTH, AND HARVEST OF NORTHERN PIKE IN ESCANABA LAKE AFTER IMPLEMENTATION OF A 22-INCH SIZE LIMIT

By
James J. Kempinger and Robert F. Carline

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CONTENTS

2 **INTRODUCTION**

3 **DESCRIPTION OF STUDY AREA**

3 **METHODS**

Population, Exploitation and Growth, *3*
Harvest, *3*

4 **FINDINGS**

Population Density, *4*
Total Mortality, *5*
Fishing Pressure, Harvest, and Exploitation Rates, *5*
Growth Rates, Maturity and Condition Factors, *6*

9 **DISCUSSION**

Population Density and Growth, *9*
Sport Fishery, *11*
Equilibrium Yield, *11*

13 **SUMMARY**

14 **APPENDIX A: Known Macrophytes Present in Escanaba Lake**

14 **APPENDIX B: Known Fish Species Present in Escanaba Lake**

15 **LITERATURE CITED**

Northern pike are not native to Escanaba Lake. Fry were introduced in the 1930's and the population became established in the mid 1950's. This lake was open year-round to fishing with no bag or size limits from 1946-1963. A 22-inch minimum size limit was imposed on northern pike in 1964.

INTRODUCTION

Size limits have been imposed on northern pike *Esox lucius* Linnaeus populations in Wisconsin waters since 1909. Historically, the first length limits were applied statewide (Table 1) and ranged from 12 to 20 inches. From 1954 to 1959, Wisconsin completely eliminated size limits on northern pike. The period 1959 to date has been characterized by regional minimum size limits, a 22-inch limit in the southeast, 18 inches in the northwest, and no size limit in the remainder of the state. Changes in size limits on northern pike probably reflect changing public attitude rather than new findings. Among lay people and fishery managers alike, there has been considerable difference of opinion on the efficacy of size limits in increasing harvests. This interest in using size limits to improve northern pike harvests provided the impetus for this study.

TABLE 1. *History of northern pike size limits in inland waters of Wisconsin.*

Year	Size Limit Inches
1909	12
1917	16
1936	20
1937-52	18
1953	13
1954-59	None
1959	*22
1966	**18

*Specified counties in southeastern Wisconsin
**Specified counties in northwestern Wisconsin

Minimum size limits on fish may be implemented for a variety of reasons: e.g. restore a failing fishery, increase total catch from a healthy fishery, effect a change in size of harvested fish, etc. The objective of this study was to see if the population and the harvest of 'large' northern pike could be increased through the application of a length limit. It was also an opportunity to observe the effect of protecting northern pike and resultant increased predation upon the panfish community. Escanaba Lake was chosen for this study because a compulsory fishing permit system had been in effect since 1946, there was a long record of harvest and fish population data, and no size limits had ever been imposed. The 22-inch size limit on northern pike was implemented in 1964 and analysis of the size limit was based on harvest and population parameters for 5 years (1959-63) with no regulations and for 9 years (1964-72) with the length limit.

While Escanaba Lake provided an apparently ideal setting in which to conduct the study, a major change in structure of the fish population occurred during the 1960's that complicated interpretation of the results. Panfish densities attained high levels in the late 1950's and subsequently declined to low levels by 1966 (Kempinger and Carline 1977). Although it was not apparent at the time, the size limit was implemented during a period of panfish decline.

DESCRIPTION OF STUDY AREA

Escanaba Lake is located on undeveloped, state-owned land in the Northern Highland region of central Vilas County. It covers an area of 293 acres, has a shoreline of 5.1 miles and a maximum depth of 26 ft. (Kempinger et al. 1975). Shoreline and bottom contours are irregular and there are several islands with rock bars and shoals. An inlet and outlet are present at high water stages, but migration of fish is unlikely. Total alkalinity of surface waters ranges from 16 to 19 ppm and pH ranges from 6.2 to 7.3. Blooms of phytoplankton are common and aquatic macrophytes are present in the shallow areas (Append. A). The sport fish community includes most warm water fishes commonly found in the region (Append. B).

The northern pike was not native to Escanaba Lake. Between 1937 and 1941, approximately 547,000 northern pike fry were stocked. The first natural reproduction that created a sizeable year-class occurred in 1956. Successful reproduction in subsequent years led to the establishment of northern pike as a major predator in the lake. From 1946-56, only eleven northern pike had been harvested. By 1959 northern pike accounted for 15% (5.7 lb/acre) of the total yield, while yields of walleye (3.8 lb/acre), yellow perch (8.1 lb/acre), and pumpkinseed (14.5 lb/acre) accounted for an additional 70% of the total.

METHODS

POPULATION, EXPLOITATION AND GROWTH

Northern pike were captured with fyke nets during the spring spawning season and were marked by fin removal or by affixing an aluminum strap tag to the preopercular bone. Ages were determined from scales collected at time of marking. From 1957-63, densities of Age 1+* males and Age 2+ females were estimated by the Petersen method. Proportions of marked fish in the population were determined from the sport fishing harvest. After the size limit went into effect, it was possible to estimate only the number of northern pike over 22 inches using the Petersen method. Densities of fish less than 22 inches were then estimated using the Schnabel method. Netting periods ranged from 6 to 12 days. Prior to 1964, standing crops of northern pike were calculated by multiplying the average weight of harvested fish by the spring population estimate. After implementation of the size limit, standing crops were calculated by determining mean length of fish caught in nets, converting length to weight, and multiplying by the population density.

Total annual mortality rates for individual year classes were calculated from catch curves (Ricker 1975). Instantaneous total mortality rates (Z) were estimated from the slope of the regression of age and natural log of fish numbers. Mortality rates for the 1957 and 1958 year classes were calculated using population estimates at successive ages. For the 1962-66 year classes, numbers of northern pike captured in fyke nets were used to construct catch curves. Exploitation rates were estimated from the proportion of marked fish caught by anglers. Exploitation rates were calculated for individual cohorts from 1957-63 and for fish over 22 inches from 1964-72. Instantaneous rates of natural mortality (M) were calculated following Ricker (1975). Estimated mean weights of northern pike Ages 2-8 from 1961-62 were used to calculate instantaneous growth rates (G). Total lengths in inches (TL) and weights in pounds (W) of northern pike caught throughout the fishing season were used to calculate condition factors (R):

$$R = \frac{W \times 10^5}{TL^3}$$

HARVEST

Harvest data were obtained through a compulsory permit system. Permits were issued to anglers without charge at a checking station located at the only landing on the lake. At the end of each trip, anglers submitted their catch for inspection by Department personnel, fishing hours were recorded, and scale samples were obtained from all fish. Marks were recorded for population and exploitation rate calculations. All fish were measured to the nearest 0.1 inch total length (TL) and weighed to the nearest 0.01 pound

In this report, the fishing year is considered to begin and end with the disappearance of ice cover in the spring, usually between April 15 and 30, and therefore consists of a season of open-water fishing plus the winter fishing season immediately following.

Harvest data were analyzed with respect to both numbers and total weights of fish caught. To avoid confusion we have adopted the convention whereby 'catch' refers to numbers of fish harvested and 'yield' refers to their total weight.

*Plus sign should be read as 'and all older age groups'.

FINDINGS

POPULATION DENSITY

The northern pike population from 1959-63 was sustained mostly by two strong year classes. The first known reproduction by northern pike occurred in 1956, but few of this cohort were captured in nets. The first large year class was produced in 1957 and this age group accounted for over 90% of the total population in spring, 1959. The 1958 and 1959 year classes were weak, hence the adult population decreased from 1959-61 (Fig. 1, Table 2). When the strong 1960 year class recruited to the fishery in 1962, the adult population increased by nearly 400 percent. Recruitment of the 1961 year class was exceeded by total mortality of Age 3 fish, so that the adult population declined from 1962-63. Population biomass closely paralleled density from 1959-63 and ranged from 1.7 to 8.9 lb/acre annually.

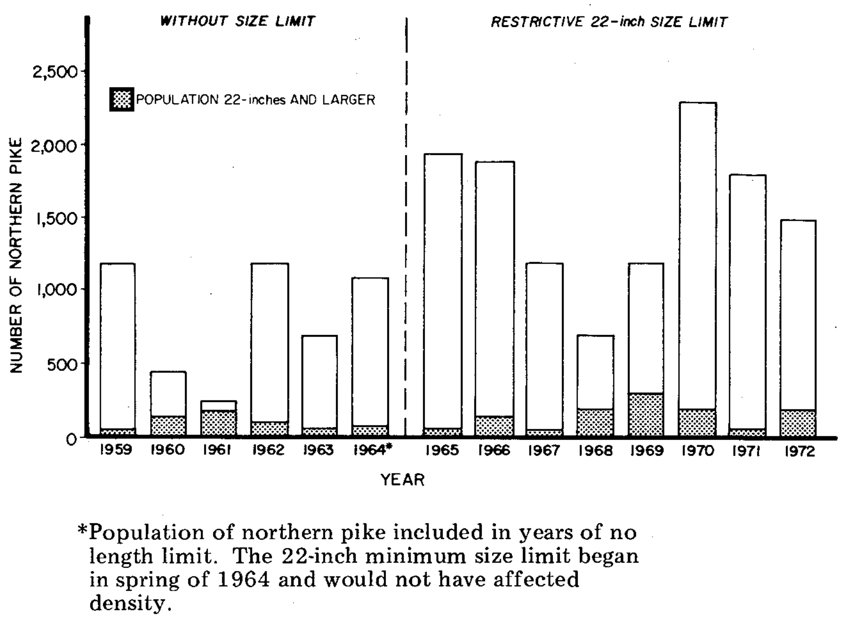


FIGURE 1. *Northern pike population estimates, Escanaba Lake.*

TABLE 2. *Estimated spring density and standing crop of northern pike in Escanaba Lake.*

	Number				Weight (lbs.)			
	All Sizes		22 Inches and Over		All Sizes		22 Inches and Over	
Year	Total	Per Acre	Total	Per Acre	Total	Per Acre	Total	Per Acre
1959	1,200	4.1	45	0.1	2,600	8.9	130	0.3
1960	450	1.5	140	0.5	1,600	5.5	460	1.7
1961	250	0.9	190	0.6	500	1.7	520	2.0
1962	1,200	4.1	100	0.3	2,100	7.2	380	1.4
1963	700	2.4	70	0.2	900	3.1	210	0.7
1964*	1,100	3.8	80	0.3	990	3.8	250	0.9
Average (1959-64)	817	2.8	104	0.3	1,448	4.9	325	1.2
1965	1,950	6.7	70	0.2	2,635	9.0	200	0.7
1966	1,900	6.5	140	0.5	2,280	7.8	400	1.4
1967	1,200	4.1	40	0.1	1,800	6.1	100	0.3
1968	700	2.4	200	0.7	1,225	4.2	500	1.7
1969	1,200	4.1	300	1.0	1,800	6.1	800	2.7
1970	2,300	7.8	200	0.7	2,300	7.8	500	1.7
1971	1,800	6.1	70	0.2	2,250	7.7	200	0.7
1972	1,500	5.1	200	0.7	2,250	7.7	600	2.0
Average (1965-72)	1,569	5.2	153	0.5	2,067	7.1	413	1.4

*Population of northern pike included in years of no length limit. The 22-inch minimum size limit began in spring of 1964 and would not have affected estimated density during the spawning season.

Spring population estimates from 1964-72 were determined from multiple mark-recapture procedures. During this period growth rates were declining and age at maturity was increasing. On the basis of fyke net catches (Table 3), it appeared that northern pike were not fully vulnerable to the nets until Age 4, whereas during the early part of the study they were fully vulnerable at Age 2. Therefore, Schnabel estimates from 1964-72 are useful for assessing numbers of mature fish, but underestimate total population size. Even though estimates are negatively biased, it is apparent that the population increased substantially after implementation of the size limit (Table 2). The mean population size from 1965-72 (1,569) was 92 percent greater than the 1959-64 mean (817), and population biomass increased by 43%. Most of the increase in population size was due to fish less than 22 inches. Mean numbers of fish under 22 inches increased by 99% while those over 22 inches increased by 47%.

We did not attempt to estimate densities of individual age groups after 1964, because of the difficulties in aging older fish and the uncertainties of when age groups were fully vulnerable to netting. The problem of comparing recruitment rates before and after 1964 was further complicated by differences in fishing mortality of Ages 1-3 northern pike. Year classes produced from 1962-66 were all well represented in net catches, but cannot be readily compared to population estimates of year classes prior to 1964 (Table 3). It is apparent that there were no year class failures after the size limit went into effect, and recruitment to maturity was probably as good as it was prior to 1964.

TOTAL MORTALITY

There was a substantial increase in total annual mortality of northern pike after the size limit went into effect. Mortality rates of fish from the 1957 and 1958 year classes were about 60%, but it should be noted that estimated densities of the 1958 year class were based on small sample sizes and 95% confidence limits were broad (Table 3). Mortality rates of the 1962-66 year classes continually increased from 69% to 91%. Much of this was natural mortality, because after the size limit went into effect, only a small proportion (about 10%) of the population was subjected to fishing mortality. It is conceivable that total mortality would have increased, even if a size limit had not been implemented, because during the early years of study the population was in the process of building up.

FISHING PRESSURE, HARVEST, AND EXPLOITATION RATES

Fishing pressure in Escanaba Lake was influenced by availability of panfish. Prior to 1964, yellow perch and pumpkinseed were sufficiently abundant to attract fishermen, and fishing pressure was high, ranging from 63 to 90 hr/acre (mean = 75) (Table 4). By 1965, panfish densities had declined and fishing pressure dropped to a mean of 44 hr/acre from 1964-72. It is unlikely that the decline in fishing pressure was directly related to implementation of the size limit, because panfish were the most sought after fishes in the lake.

Implementation of the 22-inch size limit severely limited the number of legal size northern pike available to anglers and catches declined commensurately. From 1959-63, anglers harvested an average 2.0 northern pike/acre at a catch rate for all sizes of 2.7/100 hr (Table 5). With the size limit, average annual catch fell by 84% and average yield declined 73%, from 3.2 to 0.9 lb/acre (Table 6). The reduc-

TABLE 3. *Mortality rates of northern pike calculated as the slope of age versus $\log_e$ of fish numbers. (Numbers of fish shown for the 1957 and 1958 year classes are population estimates; lower and upper 95% limits are in parentheses. Those for the 1962-66 year classes are numbers of fish captured in fyke nets in spring.)*

Year Class	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Ages Used to Calculate Mortality	Correlation Coefficient	Instantaneous Rate of Total Mortality (Z)	Total Annual Mortality (%)
1957	1,213 (1,140-1,286)	511 (439-583)	132 (112-152)	90 (68-112)			2-5	-0.98	0.915	60
1958		128 (0-360)	49 (33-65)	21 (0-43)			3-5	-0.99	0.903	59
Means									0.910	60*
1962	370	466	451	163	44	1	4-7	-0.99	1.163	69
1963	1	144	245	188	19	4	4-7	-0.96	1.463	77
1964	394	112	163	161	28	1	4-7	-0.92	1.703	82
1965	1	34	184	124	2	1	4-7	-0.94	1.977	86
1966	6	194	339	108	3		4-6	-0.96	2.363	91
Means									1.734	82*

*Calculated from mean Z.

tion in catch was probably unrelated to reduced fishing pressure (Fig. 2, line fitted by least squares), because from 1958-63 total catch of all sizes of fish and fishing pressure were poorly correlated (r^2 = 0.35). However, during the same period northern pike density in spring and total catch were strongly correlated (r^2 = 0.78). Thus, the reduction in northern pike harvest after 1964 was due to the decreased numbers of legal size fish available; i. e., a mean of 0.5 fish/acre 22 inches and over compared to 2.8 fish/acre of all sizes prior to imposition of the size limit.

Implementation of the size limit did not result in a substantial increase in harvest of northern pike over 22 inches. Mean annual total catch of pike over 22 inches decreased slightly from 98 to 93 fish, although catch rate increased from about 0.4 to 0.8 fish/100 hrs (Table 5). Mean lengths and weights of pike harvested prior to 1964 were less than after the size limit. Mean weights and lengths of pike over 22 inches declined from 3.4 to 2.7 lb and 24.2 to 23.3 inches, respectively, and mean yield dropped from 334 to 255 lb (1.1 to 0.9 lb/acre). Thus, the only fishery statistic that increased after the size limit went into effect was the catch rate of pike over 22 inches. All other fishery statistics declined, most notably total yield and mean size of pike over 22 inches.

Fishing mortality accounted for most of the total mortality prior to 1964. Exploitation rates ranged from 27 to 64% (mean = 46) while total mortality was estimated at 60%. Because of their rapid growth, northern pike recruited to the fishery at an early age, males as Age 1 and females as Age 2. For fish Age 2 and older, exploitation rates remained approximately the same throughout their life. After the size limit was implemented, mean exploitation rate of legal size fish was 44%, nearly the same as prior to 1964 (Table 4). However fish over 22 inches accounted for about 10% of the mature population, so that exploitation rate of all mature fish was about 6%. From 1964-72 mean total mortality was 82%; hence, mean rate of natural mortality was 76%, substantially greater than the mean of 14% prior to 1964.

GROWTH RATES, MATURITY AND CONDITION FACTORS

After the size limit was implemented, population density of northern pike increased, and growth rates declined. Prior to 1964 most fish reached 22 inches at Age 4 (Table 7). In subsequent years growth rates declined and it was increasingly difficult

TABLE 4. *Total fishing pressure and rates of exploitation of northern pike in Escanaba Lake during the periods under no size limits (1958-63) and under the 22-inch size limit (1964-72).*

Year	Fishing Pressure		Rate of Exploitation
	Hours	Hours/Acre	
1958	26,368	90	0.50
1959	21,979	75	0.64
1960	22,214	76	0.27
1961	18,497	63	0.44
1962	22,367	76	0.49
1963	20,796	71	0.45
Average (1958-63)	22,037	75	0.46
1964	12,769	44	0.40
1965	10,775	37	0.53
1966	13,716	47	0.56
1967	14,437	49	0.42
1968	9,898	34	0.31
1969	11,150	38	0.53
1970	14,695	50	0.52
1971	16,246	56	0.45
1972	11,271	38	0.24
Average (1964-72)	12,773	44	0.44

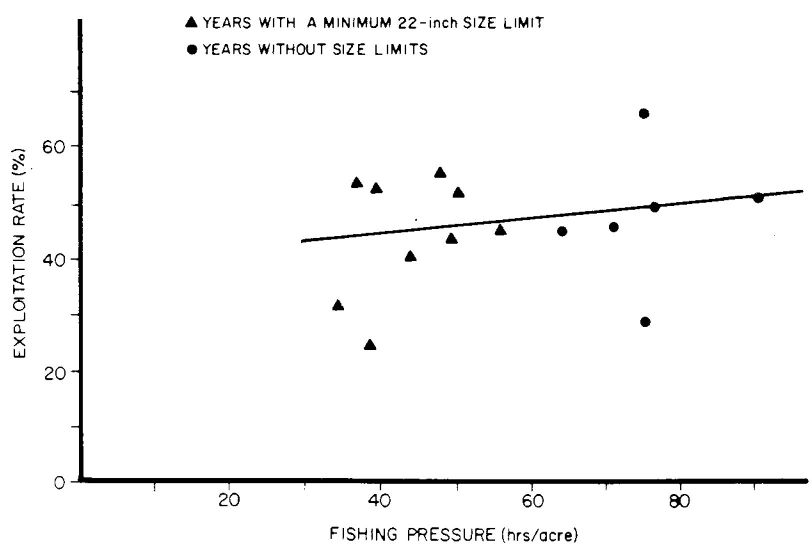


FIGURE 2. *Relation of fishing pressure (1958-72) to annual exploitation of legal northern pike in Escanaba Lake.*

TABLE 5. *Fishing success and catch of northern pike from Escanaba Lake.*

	Northern Pike 22 Inches and Larger				Total Catch			
Year	No.	Per Acre	Per Hour	Avg. Size* (inches)	No.	Per Acre	Per Hour	Avg. Size* (inches)
1958	44	0.1	0.002	23.4	935	3.2	0.035	16.0
1959	155	0.5	0.007	23.7	882	3.0	0.040	19.8
1960	97	0.3	0.004	24.1	152	0.5	0.007	22.8
1961	98	0.3	0.005	24.4	294	1.0	0.016	19.3
1962	122	0.4	0.005	25.3	691	2.3	0.031	19.6
1963	70	0.2	0.003	23.6	638	2.2	0.031	17.5
Avg.	98	0.3	0.004	24.2**	599	2.0	0.027	18.4**

	Northern Pike with 22 Inch Minimum Size Limit			
Year	No.	Per Acre	Per Hour	Avg. Size* (inches)
1964	62	0.2	0.005	23.4
1965	70	0.2	0.006	23.3
1966	70	0.2	0.005	23.5
1967	31	0.1	0.002	23.1
1968	81	0.3	0.008	22.9
1969	217	0.7	0.019	23.3
1970	148	0.5	0.010	23.2
1971	62	0.2	0.004	23.1
1972	103	0.3	0.009	23.4
Avg.	93	0.3	0.008	23.3**

*Total Length
**Weighted Average

TABLE 6. *Yield (pounds) of northern pike from Escanaba Lake.*

	Northern Pike 22 Inches and Larger			Total Yield		
Year	Weight	Per Acre	Avg. Weight	Weight	Per Acre	Avg. Weight
1958	140	0.5	3.2	928	3.2	1.0
1959	513	1.8	3.3	1,680	5.7	1.9
1960	328	1.1	3.4	446	1.5	2.9
1961	339	1.2	3.5	582	2.0	2.0
1962	465	1.6	3.8	1,219	4.2	1.8
1963	217	0.7	3.1	834	2.8	1.3
Avg.	334	1.1	3.4	948	3.2	1.6

	Northern Pike with 22 Inch Minimum Size Limit		
Year	Weight	Per Acre	Avg. Weight
1964	193	0.7	3.1
1965	197	0.7	2.8
1966	194	0.7	2.8
1967	83	0.3	2.7
1968	205	0.7	2.5
1969	577	2.0	2.7
1970	380	1.3	2.6
1971	155	0.5	2.5
1972	307	1.0	3.0
Avg.	255	0.9	2.7

to accurately read scales from Age 5+ fish; however, it appeared that near the end of the study most northern pike did not reach 22 inches until Age 8. Reduced growth rates delayed maturity. Before 1964, males first matured as Age 1 and females as Age 2. By 1967 males first matured at Age 3 and females at Age 4.

The best quantitative information we have on reduction in growth rates is from Ages 1-3 northern pike. Average lengths of these age groups in 1958-64 were consistently larger than those from 1965-72 (Table 8). An Analysis of Variance was applied to the yearly average length data for Age 2 and 3 northern pike (using all values except those in parens where sample size was less than 5). This showed the 1965-72 group to be significantly shorter ($P < .01$ for males; $P < .05$ for females,) than those before the 22-inch size limit, in 1958-64. Age 2 and 3 males were 19 and 20% shorter, respectively, and females were 22 and 13% shorter. By weight, the size reduction was 38% and 55% for Age 2 and 3 males.

To standardize the expression of weight loss in terms of condition factors, these were plotted for the years

TABLE 7. *Mean total lengths (TL) of mature and immature male and female northern pike captured in fyke nets during spring.**

Year	Age 2	3	4	5	6	7	8
1961	13.4	21.1	22.5	24.4	26.2	28.0	30.5
1962	15.3	18.1	20.1	23.7	26.1	26.8	29.3
1963	14.7	18.3	21.1	23.6	25.6		
Mean TL (inches)	14.5	19.2	21.2	23.9	26.0	27.4	29.9
Mean Calculated Weights (lb.)	0.63	1.55	2.13	3.14	4.11	4.87	6.45

*Mean weights were calculated from the equation: $\text{Log}_e W = -9.07 + 3.218 \text{Log}_e L$, where W is mean weight in pounds and L is total length in inches. Data for regression equation were taken from harvested fish, 1961-63.

TABLE 8. *Mean total length (inches) of northern pike, Ages 1-3, in Escanaba Lake.*

Year	Age 1 Male	Age 1 Female	Age 2 Male	Age 2 Female	Age 3 Male	Age 3 Female
1958	12.1		20.2			
1959			17.8	19.7	20.6	21.2
1960	(15.1)*		(16.4)		21.1	23.8
1961	13.4		(21.2)	(23.5)	(21.0)	(25.3)
1962	14.1		16.9		22.7	(20.5)
1963	(13.6)		15.6	18.6	19.2	17.3
1964**	(11.8)		15.5		19.6	
Average (1958-64)	13.2		17.2	19.2	20.6	20.8
1965	13.3		(20.1)		18.7	20.6
1966	(12.7)		15.3	16.2	16.6	(17.8)
1967					16.0	18.4
1968					17.4	(17.5)
1969			12.6	15.2	15.5	18.0
1970	(11.7)		13.1	(14.1)	14.9	17.2
1971			14.4		16.0	17.3
1972					17.2	17.4
Average (1965-72)	13.3		13.9	15.7	16.5	18.2

*( ) Less than 5 fish in sample; not included in average.

** Growth of northern pike included in years of no length limit. The 22-inch minimum size limit began in spring of 1964 and would not have affected growth rate.

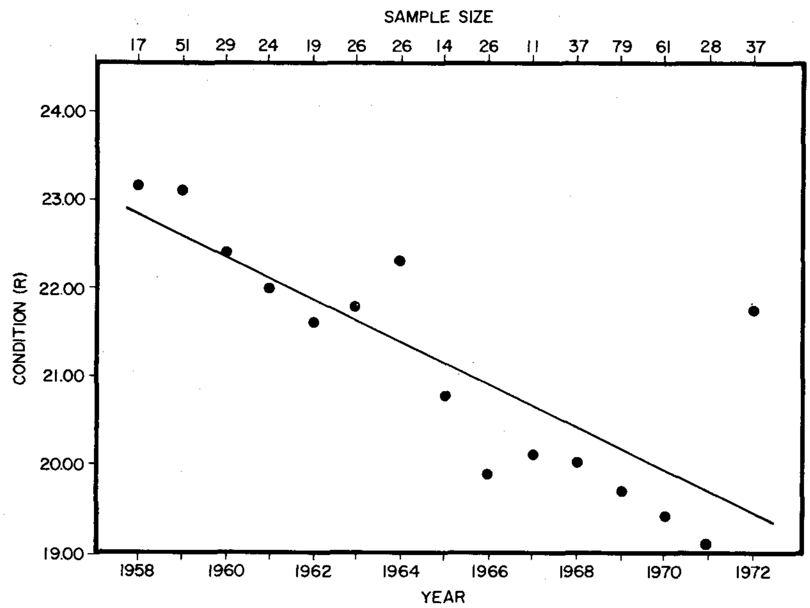


FIGURE 3. *Mean condition factor of angler-caught northern pike in Escanaba Lake. Data taken from fish between 22.3 and 23.2 inches in total length.*

1958-72 for fish measuring 22.3-23.2 inches only (Fig. 3). Condition steadily declined (trend line fitted by least squares) except for the years 1964 and 1972 when there were unusually strong year classes of perch. Whether the size limit extended the decline that typically occurs in years following establishment of a fish population is unknown. At any rate the size limit seemed not to forestall this decline.

DISCUSSION

Development of the northern pike population in Escanaba Lake had a marked effect on the sport fish community (Kempinger et al. 1975; Kempinger and Carline 1977). Changes in abundance of prey species, in turn, had an influence on northern pike. Interpretation of data on effects of the size limit must be made in light of these changes in the fish community.

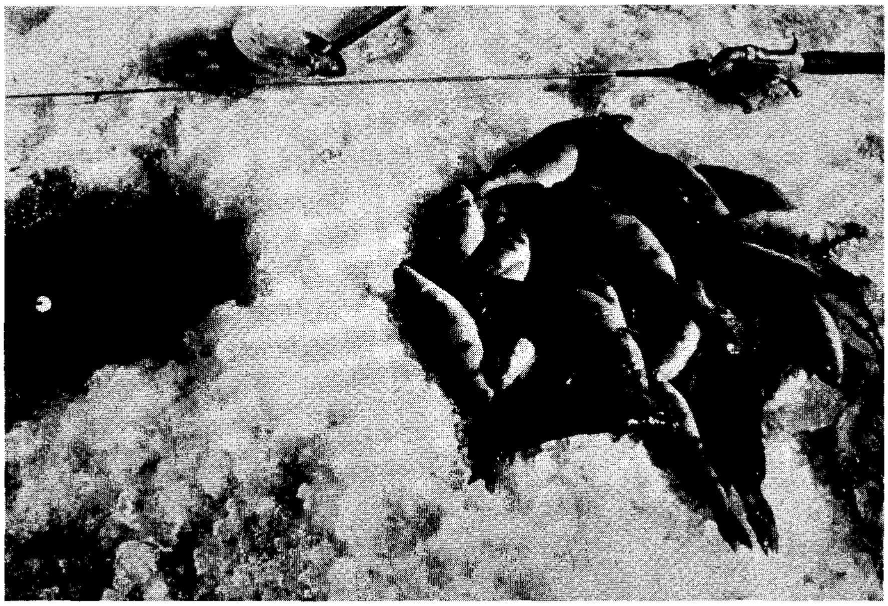
POPULATION DENSITY AND GROWTH

Density of northern pike increased by at least 90% after the size limit went into effect. Because of the difficulty in estimating numbers of immature fish, we could not define the exact magnitude of this increase. However, it appears that the increased number of northern pike was due not only to a reduction in fishing mortality, but also to changes in rates of natural mortality and recruitment.

Prior to 1964, fishing mortality (46%) accounted for much of the total annual mortality (60%). Although fishing mortality on legal size fish changed little after the size limit was implemented, the impact of fishing on the entire population was negligible, about 6% were harvested annually. Because the actual population was probably greater than the estimated population, actual fishing mortality must have been less than 6%. A major consequence of the size limit was a substantial reduction in fishing mortality.

The gradual increase in total mortality from 1964-72 was due to natural mortality. Prior to 1964 natural mortality was about 14%. Based on the average exploitation of 6% and average total mortality of 82% (Table 3), natural mortality increased to about 76% from 1964-72. Therefore, decreased fishing mortality as a result of the size limit was more than compensated for by an increase in natural mortality, from 14 to 76%.

We were unable to determine changes in recruitment rates, because after the size limit went into effect growth rates declined, age at maturity increased, and vulnerability to capture by fyke nets of Ages 1-3 fish changed. However, if we assume the population was in a steady state, recruitment rates can be estimated from average total mortality rates and population sizes



When yellow perch along with other panfish species declined in Escanaba Lake, so did the fishing pressure. The increase in density of northern pike attributed to the prey decline

prior to and after 1964. Mean population density prior to 1964 was 817 and total annual mortality was 60%. In a steady state, annual recruits would equal annual deaths, so the expected number of recruits would be: 817 × 0.60 = 490. From 1964-72 mean density was 1,569, mean total mortality was 82%, so that expected recruitment would have been: 1,569 × 0.82 = 1,287; a 162% increase over presize-limit recruitment. This should be a minimum estimate of recruitment, because population estimates represent mature fish and age at maturity increased by about 2 years after the size limit was implemented.

The increased recruitment after 1964 was probably unrelated to the size limit. Although densities of adult northern pike increased after 1964, we do not believe that an increased number of spawners led to improved recruitment, because a relatively small number of adult pike are capable of producing large year classes. For example, the large 1957 year class was produced by a population of adults that were too sparse to permit estimation of their density. If year class production by northern pike was most influenced by abiotic factors as in some walleye populations (Busch et al. 1975), then increased recruitment after 1964 may have been due to the vagaries of climatic conditions.

Based on mean lengths of Ages 1-3 northern pike, condition factors, and age at maturity, it was clear that growth rates declined substantially after the size limit went into effect. Reduced growth rates occurred as population density increased, suggesting that growth was density-dependent and that the food supply was being effectively cropped by northern pike. In recent summaries of changes in the sport fish community of Escanaba Lake, it has been suggested that establishment of the northern pike population, adding to the already dense population of walleyes, was responsible for high mortality of juvenile centrarchids and yellow perch (Kempinger et al. 1975; Kempinger and Carline 1977). From 1959-72 only one year class of yellow perch survived in sufficient numbers to have an impact on catch rates of the sport fishery. Over this period of 13 years none of the four species of centrarchids produced a year class that influenced the sport fishery. We have suggested that a small number of prey adults were able to produce enough juveniles to sustain walleye and northern pike populations, but mortality on juvenile prey was sufficiently high to allow only a small number to survive to adulthood.

Changes in condition factors of northern pike provided additional evidence that declining growth rates were related to reduced food supply. From 1958-72 there was a continual decline in condition factors of northern pike with the exception of 1964 and 1972. During those two years walleye fingerlings exhibited the fastest growth that has been recorded from 1958-72. Juvenile yellow perch were the predominant food of walleye fingerlings, and growth rates of walleye were directly related to perch density (Morsell 1970). Thus, the relatively high condition factors of northern pike during these years was likely due to an improved food supply.

If the hypothesis that predation by northern pike significantly influenced survival of juvenile centrarchids and yellow perch is correct, then reductions in prey populations and a decline in growth rates of northern pike would be likely outcomes. Aquatic vegetation in Escanaba Lake is confined to protected bays, while much of the shoreline offers little protective cover for prey species. This apparent lack of cover coupled with increasing northern pike densities in the mid 1960's could account for drastic declines in abundance of perch and centrarchids.

If one accepts the hypothesis that increased densities of northern pike caused the decline in forage fish, the next question is 'did establishment of the size limit contribute to the continued decline of panfish populations?' — a question that can not be resolved at present. It was clear that the size limit resulted in a marked reduction in fishing mortality. However, the reduction in fishing mortality was more than compensated for by increased natural mortality. The process that the size limit did not influence, yet was most important, was recruitment, which more than doubled after 1964. The compensatory increase in natural mortality after 1964 may have been more of a response to increased recruitment than it was to decreased fishing mortality. If recruitment had not increased during the study, it would have been possible to determine if the size limit enhanced

TABLE 9. *Northern pike harvest, population and exploitation rates from selected lakes.*

Lake	Acreage	Regulation	No. of Years	Harvest			No. of Years	Population			Exploitation Rate
					No./Acre	Lb./Acre			No./Acre	Lb./Acre	
Escanaba, Wisconsin	293	No Size Limit	6	Range	0.5-3.2	1.5-5.7	6	Range	0.9-4.1	1.7-8.9	0.27-0.64
				Avg.	2.0	3.2		Avg.	2.8	4.9	0.46
		Size Limit 22 inches	9	Range	0.1-0.7	0.3-2.0	8	Range	0.1-1.0	0.3-2.7	0.24-0.56
				Avg.	0.3	0.9		Avg.	0.5	1.3	0.44
Murphy Flowage, Wisconsin	180	No Size Limit	15	Range	0.9-4.5	1.8-11.5	15	Range	2.4-49.2	4.5-54.5	0.03-0.50
				Avg.	2.8	6.0		Avg.	10.9	15.6	0.26
Nebish, Wisconsin	94	No Size Limit	21	Range	0.01-0.6	0.04-2.7	4	Range	1.2-1.6		0.12-0.23
				Avg.	0.2	0.9		Avg.	1.4		0.19
Bucks, Wisconsin	83	No Size Limit	1	Range	9.6	9.8	5	Range	12.4-49.3	13.3-36.8	0.15-0.21
								Avg.	31.9	26.9	0.18
		Size Limit 18 inches	2	Range		1.6-1.9	5	Range	13.3-28.0	14.9-25.8	
				Avg.	1.1	1.8		Avg.	22.8	22.1	
Heming, Manitoba	640	No Size Limit	16	Range	0.8-11.5	1.2-4.8					
				Avg.	3.4	3.0					
George, Minnesota	456	No Size Limit	3	Range	4.5-9.7	3.8-10.0					
				Avg.	7.8	7.6					
Lac Court Oreilles, Wisconsin	5,040	No Size Limit					5	Range	0.4-1.1		
								Avg.	0.8		
		Size Limit 18 inches					7	Range	1.0-2.5		
								Avg.	1.6		
Cedar & Gilbert Wisconsin	1,044	No Size Limit					2	Range	1.0-3.0		
								Avg.	2.0		

predation by northern pike on panfish populations. Resolution of this question will likely result from analysis of data collected after removal of the size limit on northern pike.

SPORT FISHERY

Northern pike was the most heavily exploited species in Escanaba Lake (Kempinger et al. 1975). Their preference for littoral habitats and voracious feeding habits probably account for their vulnerability to sport fishing. Within the range of observed fishing pressure (34-90 hrs/acre), exploitation rate of legal size fish did not change appreciably (Fig. 2); the slope of the regression equation was not significantly different than zero ($P > 0.05$). Similarly, exploitation rates of walleye in Escanaba Lake were not significantly influenced by fishing pressure (Kempinger et al. 1975).

After the 22-inch size limit went into effect there was an 84% reduction in average annual catch, and harvest of northern pike greater than 22 inches changed little. Prior to the size limit, average annual yield was 3.2 lb/acre, which was well within the range of northern pike yields reported from other waters (Table 9). High yields of northern pike from Murphy Flowage, Wisconsin (Snow 1974) and Bucks Lake, Wisconsin (Snow and Beard 1972) reflect the fact that flowages tend to be highly productive, probably because of their extensive littoral areas.

The only thorough study on size limits that can be compared to this report is that from Bucks Lake, where an 18-inch size limit resulted in an 82% decrease in yield. In our study, yield declined by 73%. Northern pike in Bucks Lake grew slower than those in Escanaba Lake, but size limits at both lakes protected pike until Age 4. It is noteworthy that in both populations total annual mortality did not decline as a result of reduced fishing mortality. Snow and Beard (1972) suggested that population size and mortality rates were a function of the food supply. Similarly, in Escanaba Lake, total annual mortality increased as forage abundance declined. However, increased mortality may have been a compensatory response to increased recruitment. We have no way of separating out the effects of food supply and recruitment on total mortality. It was clear from Bucks Lake and Escanaba Lake studies that significant reductions in harvest followed implementation of size limits on northern pike.

EQUILIBRIUM YIELD

Several mathematical models have been developed whereby one can readily examine predicted yields from different combinations of fishing intensity and age of recruits to the fishery (for review, see Gulland 1969). Accuracy of predicted yields under a given set of conditions will often depend upon how well inherent assumptions of

TABLE 10. *Equilibrium yield calculations per 790 lbs. of recruits when instantaneous growth (G) and natural mortality (M) are unchanged.*

Age of Recruits to Fishery	Approximate Size Limit (inches)	Yield (lb.)	Catch (no.)	Mean Weight of Catch (lb.)	Population Biomass (lb.)
2	14.0	1,350	930	1.45	1,820
2+	17.8	1,620	780	2.08	3,080
3	18.3	1,660	750	2.22	3,360
3+	20.8	1,800	620	2.88	4,810
4	21.1	1,810	600	3.03	5,120
4+	23.2	1,800	490	3.70	6,885
5	23.6	1,780	460	3.84	6,945
5+	24.5	1,600	360	4.45	8,370
6	25.6	1,540	340	4.57	8,640

the model are met. Ricker's (1975) equilibrium yield model can be readily used for many sport fisheries because long records of harvest are not needed and basic inputs often can be obtained within a single year. Data needed are age-specific growth rates, exploitation rates, and total annual mortality. Basic assumptions of the model are that growth rates, recruitment, and natural mortality do not change as fishing mortality and age of recruits at first harvest are varied. We used data from this study to compute the theoretical maximum yield using Ricker's model and compared the theoretical yield with actual yields.

The underlying rationale of the equilibrium yield model is that to attain maximum sustained yield, a newly recruited year class should not be exploited until it reaches maximum biomass. A year class will attain maximum biomass when instantaneous rates of growth and natural mortality are equal. Mean size of individuals at this point is defined as the critical size.

We used average instantaneous growth (1961-63) and mortality rates from 1960-63 to compute equilibrium yield. Average annual total mortality was 60% and exploitation rate was 46%. The year was divided into two intervals, May to September and September to the following May. During the May to September interval 88% of annual growth and 83% of the fishing mortality occurred. Mean weights of individual fish at midpoint of intervals were calculated assuming constant instantaneous growth rates. Catch in numbers was estimated from the quotient of yield and mean weight at interval midpoint. The annual biomass of recruits at Age 2 was taken as 790 lb, which was the mean biomass of Age 2 northern pike in 1961 and 1962.

Calculated peak yield (1810 lb) occurred when northern pike were first harvested as Age 4 (Table 10), which approximated a 21-inch size limit. However, calculated yields varied little when northern pike were first harvested between Age 3+ and Age 4+. Predicted peak yield was about 34% greater than expected yield with no size limit, and number of fish caught would be 35% less than that with no limit. In calculating equilibrium yield it is assumed that growth rates are constant and, as a year class is protected from fishing, natural morality remains unchanged. Thus, when year classes were protected to Age 4, population biomass increased from 1,820 to 5,120 lb, or a 180% increase.

The 22-inch size limit imposed on northern pike in Escanaba Lake was close to the size limit that was predicted to produce maximum yields (Table 10). However, when the size limit was in effect there was 73% decrease in yield rather than a 34% increase. Population biomass increased after 1964, but not as much as predicted, 43 vs. 180%. One of the major reasons for the difference between actual and predicted yield was a decline in growth rates.

Growth rates of Ages 2 and 3 northern pike decreased by 38 and 55%, respectively, when data from 1962-64 and 1969-71 were compared. Prior to 1964, northern pike reached 22 inches as Age 4, but after growth rates declined, they did not attain 22 inches until Age 8. Thus, the size limit protected northern pike throughout most of their life and few were eventually harvested. When we simulated a 40% decrease in growth rates and kept natural mortality and recruitment constant, the theoretical yield with a 22-inch size limit was 63% less than the yield with unchanged growth rates and no size limit — a close approximation to the observed reduction in yield.

The other two assumptions of the model that were not met were constant recruitment and natural mortality. After the size limit went into effect, recruitment more than doubled and natural mortality increased from about 14 to 76%. It would appear that these changes offset each other and that most of the reduction in yield could be accounted for through decreased growth rates.

We have suggested that protection of northern pike and their subsequent population build-up led to a decline of panfish populations, the major prey of northern pike. The limited littoral area in Escanaba Lake may have offered juvenile panfish little cover and made them vulnerable to predation. In lakes with extensive cover, protection of northern pike could conceivably lead to higher rates of predation on panfish without severely depleting their numbers.

Difference between actual and predicted yields was dramatic and this disparity, we believe, underscores the need to consider possible consequences of compensatory changes in growth or natural mortality when using the equilibrium yield model to assess effects of changing regulations. Where northern pike populations are relatively dense, the probability of compensatory declines in growth would appear high, if a size limit were implemented. Even where populations are not dense, the most prudent approach to effect a decrease in fishing mortality might be to start with a modest size limit and increase it gradually as conditions dictate.

The questions of where size limits can be used to improve harvest and how appropriate size limits should be determined will be continuing problems in management of Wisconsin waters. The effect of size limits will vary, depending upon prevailing exploitation rates, growth rates, and structure of the fish community. It seems unreasonable to assume that a single length limit can produce desirable results over a wide range of lake types and fishing pressures. Even regionally, large differences among lakes can be anticipated, so that a uniform length limit may allow excessive harvest in some lakes and under-utilization in others. We recognize that length limits can be an effective management tool, but we suggest that they be implemented only where data indicate they are necessary and even then, size limits should initially be conservative.

SUMMARY

1. This study was conducted over a 14-year period to determine changes in population density, growth, and harvest of northern pike after implementation of a 22-inch size limit.
2. After the size limit went into effect the following occurred:
   a. Mean population density of pike increased by 92% and biomass increased from 4.9 to 7.1 lb/acre.
   b. Mean population density of pike 22 inches and over increased 47% but the percent of the population in that category remained unchanged.
   c. Mean total annual mortality increased from 60 to 82%, fishing mortality decreased from 46 to 6%, and natural mortality increased from 14 to 76%.
   d. Recruitment rates more than doubled.
   e. Mean annual fishing pressure declined from 75 to 44 hr/acre, but did not apparently influence harvest of pike.
   f. Mean annual yield of pike declined from 3.2 to 0.9 lb/acre.
   g. Average catch (in numbers) of pike over 22 inches did not change appreciably, but catch rate increased from 0.4 to 0.8 pike/100 hr, and mean weight decreased from 3.4 to 2.7 lb.
   h. Growth rates of pike declined.
3. The size limit was implemented during the midst of a decline in panfish abundance, but it is not known if the size limit contributed to the continued decline in panfish. We hypothesize that initial development of the pike population precipitated the decline in panfish and that reduced growth rates of pike during the later part of the study were related to a diminishing food supply.
4. Ricker's (1975) equilibrium yield model suggested that yield could be increased by 34% with a 22-inch limit, when in fact, the observed yield declined by 73%. Reduced growth rates of pike appeared to be responsible for the difference between theoretical and observed yields.

APPENDIX A

Known Macrophytes Present in Escanaba Lake

Najadaceae — Pondweed
- *Potamogeton amplifolius*, Large-leaf pondweed
- *Potamogeton gramineus*, Variable pondweed
- *Potamogeton pusillus*
- *Najas flexilis*, Bushy pondweed

Alismaceae — Water Plantain
- *Sagittaria latifolia*, Arrowhead
- *Sagittaria teres*, Dwarf arrowhead

Butomaceae — Flowering Rush
- *Vallisneria americana*, Wild celery

Cyperaceae — Sedge
- *Scirpus acutus*, Hardstem bulrush
- *Scirpus* sp.

Pontederiaceae — Pickerelweed
- *Pontederia cordata*, Pickerelweed

Polygonaceae—*Buckwheat*
- *Polygonum natans*, Smartweed

Nymphaeaceae — Water Lily
- *Nymphaea odorata*, White water lily
- *Nuphar variegatum*, Yellow water lily

APPENDIX B

Known Fish Species Present in Escanaba Lake

UMBRIDAE-MUDMINNOW
- Central mudminnow, *Umbra limi* (Kirtland)

ESOCIDAE-PIKE
- Northern pike, *Esox lucius* Linnaeus
- Muskellunge, *Esox masquinongy* Mitchill

CYPRINIDAE-MINNOWS AND CARP
- Northern redbelly dace, *Phoxinus eos* (Cope)
- Golden shiner, *Notemigonus crysoleucas* (Mitchill)
- Common shiner, *Notropis cornutus* (Mitchill)
- Bluntnose minnow, *Pimephales notatus* (Rafinesque)
- Fathead minnow, *Pimephales promelas* Rafinesque

CATOSTOMIDAE-SUCKER
- White sucker, *Catostomus commersoni* (Lacepede)

ICTALURIDAE-FRESHWATER CATFISH
- Black bullhead, *Ictalurus melas* (Rafinesque)

GADIDAE-CODFISH
- Burbot, *Lota lota* (Linnaeus)

GASTEROSTEIDAE-STICKLEBACK
- Brook stickleback, *Eucalia inconstans* (Kirtland)

CENTRARCHIDAE-SUNFISH
- Rock bass, *Ambloplites rupestris* (Rafinesque)
- Pumpkinseed, *Lepomis gibbosus* (Linnaeus)
- Bluegill, *Lepomis macrochirus* Rafinesque
- Smallmouth bass, *Micropterus dolomieui* Lacepede
- Largemouth bass, *Micropterus salmoides* (Lacepede)
- Black crappie, *Pomoxis nigromaculatus* (Lesueur)

PERCIDAE-PERCH
- Iowa darter, *Etheostoma exile* (Girard)
- Johnny darter, *Etheostoma nigrum* Rafinesque
- Yellow perch, *Perca flavescens* (Mitchill)
- Logperch, *Percina caprodes* (Rafinesque)
- Walleye, *Stizostedion vitreum vitreum* (Mitchill)

COTTIDAE-SCULPIN
- Mottled sculpin, *Cottus bairdi* Girard

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About the Authors

Kempinger is and Carline was a fishery biologist with the Bureau of Research at Woodruff and Waupaca, respectively. Carline is now with the Cooperative Fishery Research Unit at Ohio State University, Columbus.

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