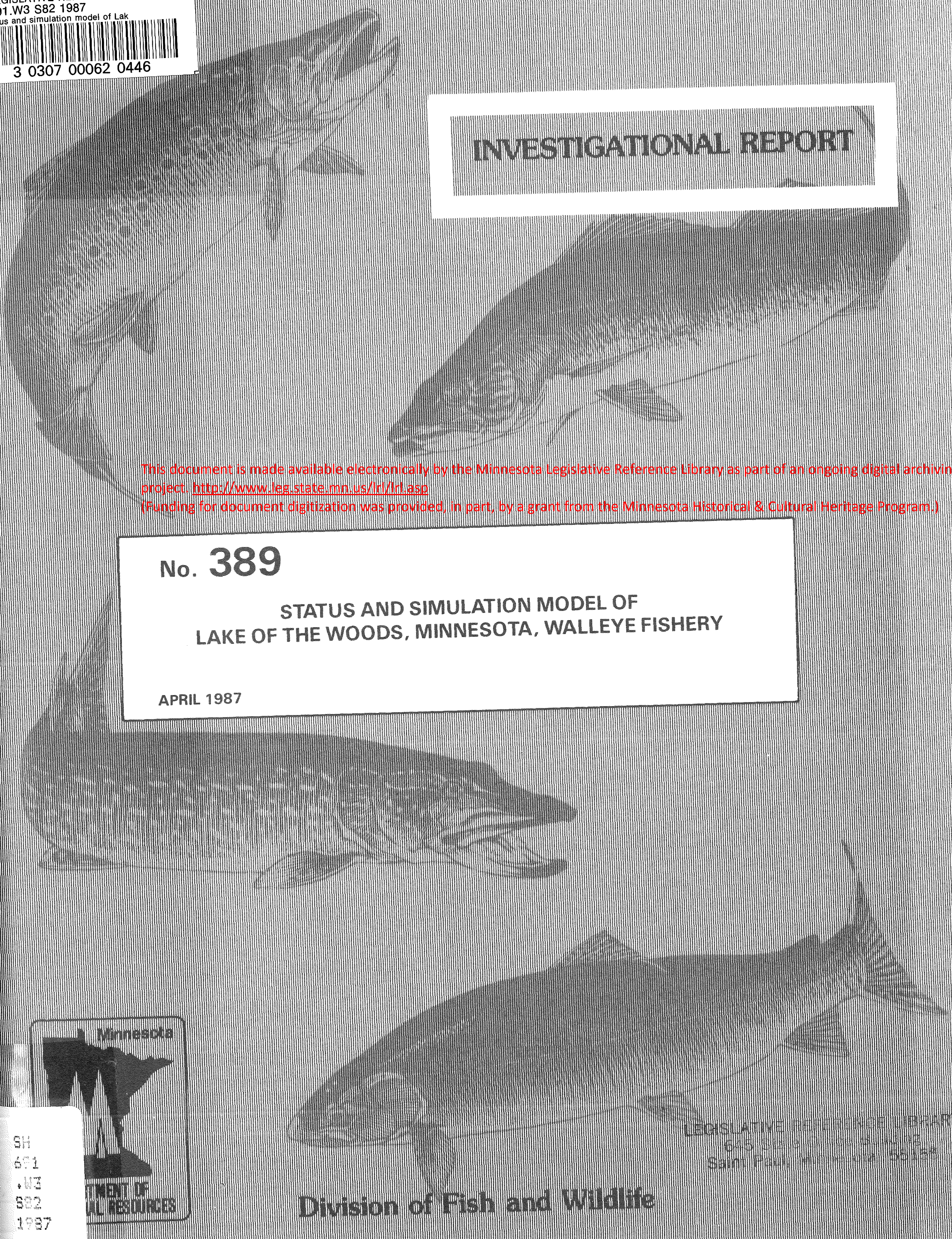

INVESTIGATIONAL REPORT

No. 389

STATUS AND SIMULATION MODEL OF LAKE OF THE WOODS, MINNESOTA, WALLEYE FISHERY

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Minnesota
DEPARTMENT OF NATURAL RESOURCES

Division of Fish and Wildlife

STATUS AND SIMULATION MODEL OF
LAKE OF THE WOODS, MINNESOTA, WALLEYE FISHERY[1]

by

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ABSTRACT

The walleye (*Stizostedion vitreum vitreum*) population in the Minnesota portion of Lake of the Woods is now supported by five to six abundant year-classes. It has stabilized since 1968-70 when it was characterized by a limited number of year-classes and widely fluctuating year-class strength. Natural reproduction is generally consistent with growth rates, ages at maturity and fecundity comparable to those documented in the 1940s and 1960s. The recruitment of an extraordinarily large 1966 year-class increased commercial catch per unit effort (CPUE) to peak levels in 1973 after which levels remained consistently high. Commercial gill net CPUE and length-frequency data from assessment netting indicated that approximately twice as many commercially legal walleye (16 in TL) are now present in the population compared to 1968-70.

Open-water angling effort by Minnesota-based anglers has increased by 17% since 1968-70 with the largest increases occurring in Manitoba (338%) and Ontario (61%) waters of the lake. Estimated pressure for all catch locations averaged 1.1 mh/A and ranged as high as 60-70 mh/A at the mouth of the Rainy River. Walleye composed 84% of the total open-water sport harvest. Angling CPUE for walleye averaged 0.39/mh for combined catch locations from 1982-84 and mean harvested weight was 1.09 lb.

Sport effort during the winter of 1982-83 increased nine-fold over average winter effort in 1968-70 and presently accounts for 11% of the annual walleye sport harvest. Sauger were most prevalent in the winter catch with CPUE increasing from 0.07 in 1968-70 to 0.68 in 1982-83 and harvest increasing 100-fold.

INTRODUCTION

Lake of the Woods supports a moderately intensive sport fishery and one of the few remaining commercial walleye fisheries in Minnesota (1985 was the last year with a commercial fishery). Initial exploitation developed around commercial pound net fisheries for lake sturgeon (*Acipenser fulvescens*) and lake whitefish (*Coregonus clupeaformis*) in 1888 (Carlander 1942). Sturgeon and whitefish populations had declined precipitously by the early 1900s resulting in a shift from impoundment gear to gill nets by commercial fishermen. The increased use of gill nets led to increased exploitation of walleye (*Stizostedion vitreum vitreum*) stocks, which replaced sturgeon and whitefish as the most important component of the commercial catch. Concurrent improved accessibility to the lake and the availability of larger outboard-powered boats increased angler exploitation of walleye stocks.

The utilization and allocation of fisheries resources on Lake of the Woods have been controversial issues for the past 50 years. Conflicts pertaining to the commercial harvest of walleye evolved between sport and commercial interests in the 1930s when commercial walleye harvests had risen to peak levels (Schupp 1974). By the early 1940s, 20% of all commercially harvested walleye in the United States originated from Lake of the Woods (Carlander 1942). Many anglers and resort owners attributed periods of poor walleye fishing to commercial operations and a policy of attrition designed to gradually eliminate commercial fishing was imposed and adhered to from 1948 to 1982. A series of investigations by Carlander (1942), Burrows (1951), Scidmore (1963), Heyerdahl and Smith (1972), Schupp (1974), and Schupp and Macins (1977) provided data and descriptions of the Lake of the Woods fisheries and the changing regulations affecting them from 1888 to 1973.

Estimated total annual sport fishing pressure by Minnesota-based anglers on Lake of the Woods was 1,116,759 mh. Combined harvest of walleye by Minnesota commercial fishermen and Minnesota-based anglers fishing both American and Canadian waters has increased by 5% since 1968-70, averaging 470,698 lb per year from 1982-84. Commercial fishermen accounted for 33% of the total walleye harvest from 1980-84 compared to 21% from 1968-70.

Total walleye mortality from different estimators ranged from 45% to 78% from 1980-84. Total walleye harvest has remained comparable to that in 1968-70 and little evidence exists to suggest a significant change in total mortality from that period. Estimates of reporting rates for tagged walleye were 68% for commercial fishermen and ranged from 33% to 45% for anglers.

Commercial exploitation of male walleye leveled off at 21in TL and peaked at 19in for females while sport exploitation peaked at 15in for males and 20in for females. Logit analysis and tag return data indicated that the total sport and commercial harvest of female walleye was dominated by the sport fishery from spring through early summer and by the commercial fishery from mid-summer through fall. This shift from sport to commercial harvest does not occur until late summer for male walleye. The commercial fishery contributed a majority of the total harvest for walleye larger than 22in TL.

A simulation model was developed to show the relative impacts of different management scenarios on the walleye population and fishery of Lake of the Woods. The process of model development provides possible explanations for trends in commercial and angling catch rates and the effects of fishing on recruitment.

Lake of the Woods walleye stocks showed signs of instability associated with excessive exploitation in the 1960s. Commercial yields and gill net catch per unit effort (CPUE) were the lowest on record, variation in recruitment had increased and yields to both sport and commercial fisheries were largely dependent on one strong year-class (Schupp and Macins 1977). Assessment netting and creel surveys in 1981 indicated that the walleye population had improved and was able to sustain current levels of exploitation by both commercial and sport fishing interests. The abundance of commercially legal walleye had increased more than two-fold since 1970, recruitment was relatively stable and the fishery was supported by several year-classes.

Despite the improved age/size structure of the walleye population, the sport fishery did not perceptibly improve. The sport harvest in 1981 was the lowest recorded in 4 years of creel data obtained since 1968 (Schupp 1974), though catch rates still substantially exceeded those from other large walleye lakes censused in recent years (Osborn and Schupp 1985). The sport catch in 1981 was dominated by three and four-year old walleye, the same age-classes providing the major share of the catch in large walleye lakes having no commercial fishery (Anthony and Jorgensen 1977).

Legislation passed in 1983 established a quota and/or buyout for commercially harvested walleye from Lake of the Woods. The quota was based on a 164,000 lb harvest in 1984, declining to 30,000 lb by 1991, after which no commercial game fish harvest would be allowed. Gill net licenses were scheduled to be permanently cancelled at the close of the 1987 license season.

The objectives of the present investigation were to: estimate the current status of exploited fish species and the fishery with respect to population vital statistics; to contrast historical conditions of the stocks with current and recent past conditions; and to simulate walleye population dynamics in a model sensitive to common fishery regulatory practices. This investigation was conducted cooperatively with the University of Minnesota.

STUDY AREA

Lake of the Woods lies on the international boundary between the Canadian provinces of Ontario and Manitoba and the state of Minnesota, USA (Fig. 1). The lake covers an area of 951,337 A, one-third of which is under Minnesota jurisdiction. The irregularly shaped basin of Lake of the Woods is 65 mi in width, 56 mi in length and lies at an approximate latitude of 49° N and longitude of 95° W.

The Minnesota portion of Lake of the Woods consists of a large, shallow, open-water expanse known as the Big Traverse which lies in the basin of glacial Lake Agassiz (Schwartz and Thiel 1963). Mean water depth is 24 ft and maximum depth approximates 39 ft. Twenty-three percent of the Big Traverse is littoral area with the bottom being comprised of soft mud flats at depths in excess of 15 ft. The Rainy River provides 78% of the inflow to Lake of the Woods. Water levels, controlled by outlet dams built for hydropower production, presently fluctuate 3-4 ft annually.

Lake of the Woods is mesotrophic. Total dissolved solids in the Big Traverse are approximately 85 ppm (estimated from total alkalinity converted to total dissolved solids using the nomograph of Ryder (1964)) and the morphoedaphic index (MEI) (Ryder 1965) is estimated to be 3.5. Most of Lake of the Woods, including the Big Traverse, does not thermally stratify (Schupp and Macins 1977). A detailed description of the lake is provided by Carlander (1942).

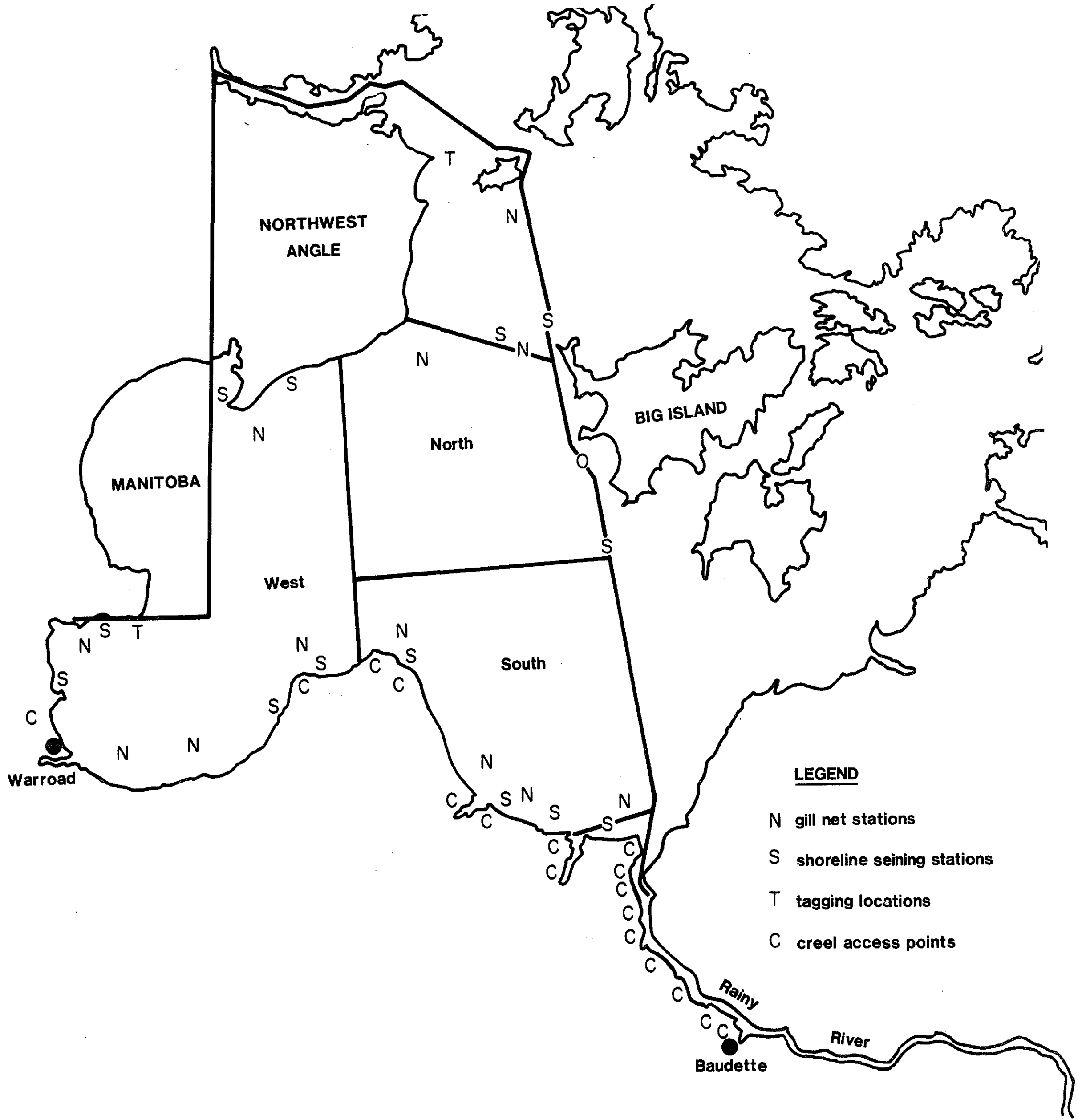


Figure 1. Assessment gill net, shoreline seining, tagging and creel survey access points, Lake of the Woods, 1980-84.

METHODS

Population Assessment

Relative abundance and size-class distribution of the fish population were estimated by systematic assessment netting on the Minnesota portion of Lake of the Woods from 1980-84. Standard experimental gill nets 250 ft in length and 6 ft deep were used. Nets were composed of five 50 ft sections of 3/4, 1, 1-1/4, 1-1/2 and 2in bar measure mesh, respectively, consistent with those used in previous investigations on Lake of the Woods (Carlander 1942; Schupp 1974).

Netting stations and procedures duplicated those established by Schupp (1974). Thirteen stations (Fig. 1) were selected to represent habitat types and water depths on the Minnesota portion of the lake. Four nets at each station were set to sample different depth strata: 6-10 ft; 10-15 ft; 15-20 ft; and >20 ft. Two netting periods, July and September, were used to provide a measure of recruitment to the fishery during the principal part of the growing season.

Total number and weight for each species were recorded by the depth of capture and summed for each depth. Lengths were recorded for all fish to the nearest 0.1in TL and weight to the nearest 0.5 oz. Scales and/or spines were taken for age and growth determination from a representative sample of each species. Sexual development of six major species, including walleye, using criteria developed by Eschmeyer (1950), was recorded during the 1983 and 1984 September netting periods to determine ages at maturity and sex ratios. Commercial catches were subsampled to obtain age and growth data for larger walleye which were proportionately underrepresented in the assessment nets.

Analysis of variance (ANOVA) and linear contrasts were used to compare CPUEs of walleye in assessment nets from 1968-70 and 1980-84. Distributions of CPUEs were skewed and indicated that a $\log_{10}$ transformation was needed to normalize data. CPUEs were derived by summing all station net catches and dividing by the total number of stations, which ranged from 4 to 13. The independent variables used in the three-way ANOVA were:

1. Year: (19)68, 69, 70, 81, 82, 83, and 84
2. Month: 7=July, 9=September
3. Depth of set: 1 = 5 to 10 ft; 2 = >10 to 15 ft;
   3 = >15 to 20 ft; 4 = > 20 ft

Since all stations were pooled to derive CPUE there were no replications and the three-way interaction of Year * Month * Depth was used for the error term with 18 degrees of freedom.

Shoreline seining was conducted to determine year-class strength of young-of-the-year (y-o-y) walleye and to estimate the relative abundance of inshore species. Three seine hauls with a 100 ft by 6 ft bag seine having 1/4in bar measure mesh were made using the fixed-pole method (Wingate and Schupp 1983) at 14 stations in 1983 and 11 in 1984 (Fig. 1). Each station was sampled four times from mid-July thru August. Seining was initiated two weeks earlier in 1984 than in 1983 after it appeared that 1983 seining had not preceded the peak catch.

Young-of-the-year game fish were measured to the nearest 1.0 mm TL and weight determined to the nearest 0.1 g. Group weights by species, growth and condition factors were determined for all game fish species. A subsample was obtained in instances where large numbers of yellow perch (*Perca flavescens*) or nongame fish were captured. Relative abundance of each species was expressed as CPUE.

The commercial fishery was monitored from 1982-84 to determine population characteristics, total harvest and number of tagged walleye in the commercial catch. The number of tags observed, length of gill net lifted, location of lift, and the length frequency and total weight of the walleye catch were recorded. Sex ratios of walleye were determined from the commercial catch in early June and from late September through October in 1983 and 1984.

Creel Survey

A creel survey using methods developed for large lakes by Schupp (1964) and incorporating the probability sampling techniques of Fleener (1972) was conducted from Minnesota access points on Lake of the Woods during each of the 1982, 1983 and 1984 open-water fishing seasons. Survey design was consistent with that used by Schupp (1974) on Lake of the Woods in 1968-70. Lake of the Woods was divided into four catch locations: Minnesota (311,000 A); Ontario (281,000 A); and Manitoba (36,300 A) waters of the lake proper; and the Rainy River to Frontier (4,015 A).

Open water creel survey work commenced with the opening of the Minnesota fishing season (Saturday nearest 15 May) and terminated in mid-October each year from 1982-84.

Eighteen departure points (resorts and public accesses) matching those from 1968-70 (Schupp 1974) were selected along the south shore of the lake and on the Rainy River. Departure points were surveyed by four creel clerks who counted boats landing and conducted interviews as anglers reached the access following a completed fishing trip. Weights, lengths and scale samples were collected from a representative sample of all species in the catch.

Sport fishing was categorized according to boat types. Fishing on Lake of the Woods occurs from small boats having limited range, and from pleasure craft and chartered launches capable of fishing any location within two hours of their operational bases. Harvest estimates were complicated due to the ability of anglers to fish Minnesota, Ontario and Manitoba waters of Lake of the Woods, the Rainy River or any combination from a single Minnesota departure point. Anglers were asked to estimate the catch and time spent fishing for each catch location. No estimate of angler harvest was made for the vicinity of the Northwest Angle.

A roving, incomplete-trip winter creel survey commenced on 1 December 1982 and was completed on 14 April 1983. The south shore of Lake of the Woods was divided into six sampling areas having good access to enable clerks to obtain house counts and angler interviews. Week days, weekend days and areas to be sampled were randomly selected. At least two sampling areas were visited per sampling period. Fish houses were counted and checked for occupancy on an hourly basis. Anglers were interviewed for length of trip, number of anglers per house or vehicle and total catch by species. Lengths were taken from a representative portion of the catch.

<u>Tagging</u>

Walleye from three locations on Lake of the Woods and one on the Rainy River were tagged in the spring of 1982 to estimate population size and exploitation rates (Fig. 1). Walleye were captured between 15 April and 6 June 1982 with a goal of marking 10,000 fish. Walleye were electrofished at the Birchdale area of the Rainy River with assistance from personnel of the Ontario Ministry of Natural Resources. A contract fisherman and MDNR personnel trap netted walleye in Four Mile Bay, while commercial fishermen were contracted to capture walleye in Muskeg and Little Traverse Bays using pound and Lake Erie trap nets, respectively. Walleye at the Birchdale site were tagged using spaghetti tags and both scale and dorsal spine samples were taken from walleye 16.0in TL. Serially numbered disc-dangler tags were attached with #20 stainless steel wire between the dorsal fins at each of the other tagging sites. Voluntary tag returns were encouraged by news releases, notification of resorts and commercial fishermen, and by posters located at sites frequented by anglers.

Walleye Population Dynamics

Fecundity analysis was conducted for 40 pre-spawning walleye (five per 1.0in length group) taken with an electrofishing boat on 21 April 1983, approximately 38 mi upstream from the mouth of the Rainy River. The second dorsal spine and scales from the area below the lateral line and adjacent to the tip of the pectoral fin were removed for age analysis. Ovaries were removed and placed in mason jars containing Gilson's fluid (Bagenal 1978). The number of eggs was estimated by a volume displacement method.

A weight-length relationship was used to predict average weight from average length for a given age. Two functions were used to depict the relationship. The first function was fitted to 288 samples from experimental and commercial gill nets during July 1983. Because few of these walleye were older than age 8, the second function was fitted to 46 walleye over 22in TL and ranging in age from 9 to 16. Both functions were of the typical form, $w = a * l_b$, where w = weight in pounds, l = length in inches, and a and b were parameters.

The total annual mortality rate (A) for walleye was estimated from a catch curve determined from assessment net catches. Age compositions were estimated from age-length keys derived individually for each biannual sampling period. Due to seasonal and year-to-year variability in the catch, all assessment net catches from 1980 through 1984 were combined. Total mortality rates were also estimated using the length-converted catch curve method developed by Pauly (1983) and by estimations from commercial and sport tag returns, where the logarithm of the number of voluntary tags reported by U.S. commercial fishermen was regressed against time for the years 1982 through 1984.

The instantaneous natural mortality rate (M) for walleye was estimated by the method of Pauly (1979). Separate growth parameters for females age 1-14 and males age 1-10 were estimated from the 1983-84 assessment net catches.

A stratified Peterson mark-recapture method was used to estimate the size of the walleye stocks vulnerable to commercial exploitation in Minnesota waters of Lake of the Woods (Chapman and Junge 1956). The four commercial gill net fisheries having the highest volunteer tag reporting rates based on return per unit effort were used to determine recaptures and to examine fish for tags. The Minnesota portion of the lake open to commercial fishing was divided into three strata to facilitate the population estimates (Fig. 1): the south stratum included the tag sites at Birchdale and Four Mile Bay; the west stratum the Elm-Buffalo Point tag site; and the north stratum the Little Traverse tag site. The number of tagged fish in each stratum which were effectively tagged (vulnerable to commercial gill nets) was estimated by comparing length frequencies of all tagged fish in each stratum with length frequencies from the four selected gill net fisheries (Ricker 1975).

Tag reporting rates for sport and commercial fishermen were derived using estimates of natural and total mortality, and of population size. The following notation was used in addition to that described in Ricker (1975):

Rate of exploitation of tagged fish vulnerable to the commercial gear:	u_v
Estimate of total number of tagged walleye harvested by U.S. commercial gear:	T_u
Commercial tag reporting rate:	R_c
Estimate of total number of tagged walleye harvested by U. S. and Ontario commercial gear:	T_c
Rate of exploitation of all tagged fish by commercial gear:	u_c
Instantaneous commercial fishing mortality:	F_c
Instantaneous sport fishing mortality:	F_s
Rate of sport exploitation of all tagged fish:	u_s
Estimate of total number of tags harvested by sport fishermen:	T_s
Sport tag reporting rate:	R_s

Logit Analysis

Tag returns from both the sport and commercial fisheries were arranged in three-dimensional cross-classified contingency tables and logits (log-odds ratios) were calculated to quantify the competitive interactions between the two fisheries (Fienberg 1980). The variable GEAR (with two categories - sport or commercial) was treated as a dichotomous response variable and two different models, each with two independent or explanatory variables, were fit to the data:

MODEL	Variable No.		Category Names
GEAR x SEASON x SEX	No. 1	Gear	Sport
			Commercial
	No. 2	Season	Spring
			Early summer
			Mid-summer
			Late summer
			Fall
	No. 3	Sex	Male
			Female
GEAR x SIZE X SEX	No. 1	Gear	Sport
			Commercial
	No. 2	Size	14-14.9 in
			15-15.9 in
			16-16.9 in
			17-17.9 in
			18-18.9 in
			19-19.9 in
			20-20.9 in
			21-21.9 in
			22-24.9 in
	No. 3	Sex	Male
			Female

The Chi Square statistic used to select the most parsimonious model (the model with the fewest interaction terms) was the G^2 or maximum likelihood statistic. After a model was selected which explained the observed distribution of tag returns in the three-dimensional table of interest, the expected cell counts or the expected number of tag returns as predicted by the model were calculated. The logits were then calculated as the log of the quantity of the expected sport cell count divided by the expected commercial cell count. A positive log mortality ratio indicated that the sport fishery contributed more to the total harvest of walleye under the restrictions defined by the values of the explanatory variables while a negative logit indicated that the commercial fishery harvested a majority of the walleye.

Simulation Model

The model, in program form, was called "WALLEYE" and was written in Applesoft BASIC stored on a 5 1/4 in floppy disk written under the Disk Operating System (DOS) version 3.3. A Users Guide appended to the back of this report provides general operational procedures, background information, a list of plotting variables, variables in the simulation program, a reference list locating the variables and parameters within the program, and the BASIC program listing for "WALLEYE". The Users Guide also contains the coding, excluding a modified version of the plotting module MICRO SIMCON (lines 9000-14000). The original MICRO SIMCON was developed by C. Walters and R. Hilborn, Institute of Animal Resource Ecology, University of British Columbia. The description of model development provides explanations of the functional relationships and parameter estimates used in the model. A list of variables was developed describing the state of the system at some point in time and rules were specified to give a system state at a fixed later time directly in terms of the initial state. Readers are referred to Holling (1978) and Hilborn et al. (1984) for further references on modeling methods logic. The model allows input for fry stocking, bag limits, size limits, season closures and tackle restrictions on an angling fishery and accounts for size and age structure, reproduction, growth and recruitment to the fishery.

The population estimates for commercially vulnerable walleye derived from the Peterson estimator (with 70% and 100% reporting rates by the four selected commercial fisheries) were used for comparison with simulation model predictions when simulated reproduction, recruitment and mortality were applied each year. Initial model development was based on the assumption that walleye stocks among the three strata in Minnesota waters were not different enough to require separate management strategies.

The simulated walleye population was initially generated from estimates of egg deposition. Due to a lack of precise knowledge on the sex ratio of adult walleye in Lake of the Woods, 50% of spawning walleye were assumed to be female in the simulated population. A linear fecundity-body weight relationship was used to estimate eggs/lb for female walleye, which was multiplied by an average weight per female and by the estimated number of female spawners to determine total egg production. Survival rates of eggs to fry were estimated from Serns (1982a) and Noble (1972), and multiplied by egg production to estimate numbers of fry produced.

The dynamic processes of fry production and natural mortality from fry to recruitment were assumed to have an average result in the model and stochasticity was avoided (for better presentation of trends) by using an estimate of the mean in the form of a constant. In the simulation model, the annual natural mortality component was assumed to be constant over time and used the following averages: 95% for age 0 (Noble 1972); 75% for age 1; and 60% for age 2 (life table approximations, Table 1). Age at recruitment was assumed constant at age 3 because growth rate to recruitment was assumed to be constant. As a result, fry production alone determined recruitment in the model and was considered synonymous with recruitment. The model provided five different options for varying fry production:

0. Constant recruitment. The same number of eggs were deposited each year and constant mortality occurred until recruitment at age 3 (line 120).

1. Egg deposition. The number of eggs deposited was directly related to the abundance of female spawners and constant mortality occurred until recruitment at age 3.

2. Ricker stock-recruitment. The number of fry produced is related to the number of spawning females in a non-linear manner. A Ricker stock-recruitment function (Ricker 1975) for walleye from Lake Erie

Table 1. Mortality schedule for walleye in Lake of the Woods, Bertalanffy function and weights from two weight-length functions.

Age	Number	Length (in)	Weight (lb)	Mortality rate (%)	Source
Eggs	34.5 billion	--	--	99.5	Noble 1972 Serns 1982
Fry	191.0 million	1.0	--	95.0	Noble 1972 Osborn 1981
1	9.6 million	5.7	0.05	75.0	Interpolation
2	2.4 million	8.6	0.19	60.0	"
3	955,000	10.7	0.38	50.0	"
4	477,500	13.1	0.70	50.0	Present study
5	238,750	15.1	1.10	50.0	" "
6	119,375	16.9	1.60	50.0	" "
7	59,688	18.5	2.10	50.0	" "
8	29,844	19.8	2.60	50.0	" "
9	14,922	21.1	3.50	50.0	" "
10	7,461	22.1	4.00	50.0	" "
11	3,730	23.0	4.60	50.0	" "
12	1,865	23.8	5.10	50.0	" "
13	933	24.6	5.60	00.0	" "
14	800	25.2	6.00	00.0	" "
15	800	25.7	6.40	00.0	" "
16	800	26.2	6.80	00.0	" "

(Koonce et al. 1983) was used for this model (line 1210) and the variables scaled to the 311,000 A of the Minnesota waters of Lake of the Woods.

3. Temperature variation. The number of fry produced was inversely linearly related to the coefficient of variation in mean daily air temperature between 15 May and 15 June 1951-1978 (Fig. 2), based on the hypothesis that variable temperatures interfered with feeding activity and increased fry mortality (Serns 1982b).

4. Combined Ricker and temperature functions. At high (2,000,000) and low (200,000) abundances of fry the Ricker function would be used, otherwise fry were assumed to be produced according to variation in spring temperature.

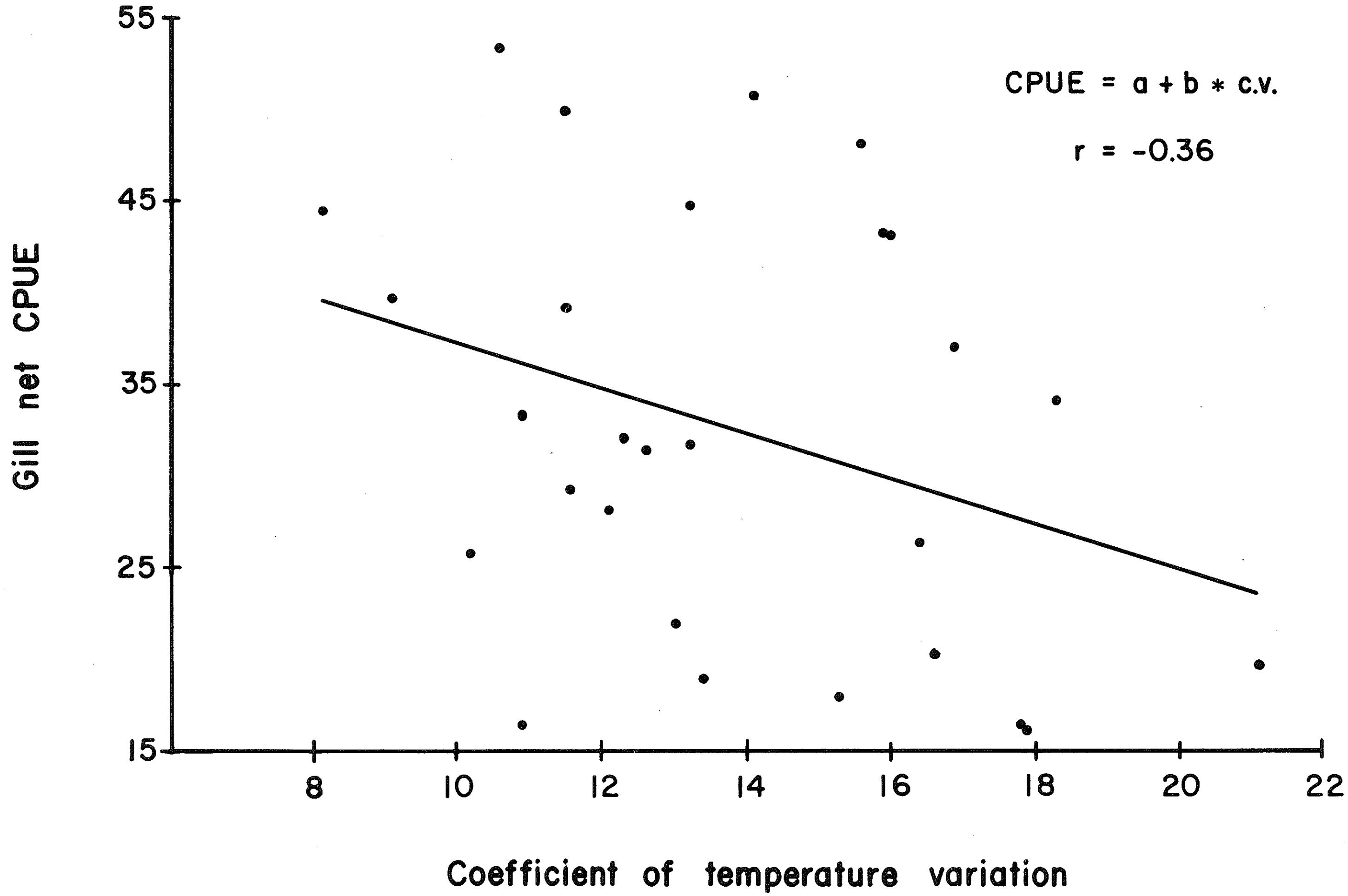


Figure 2. Relationship between the coefficient of variation of mean daily air temperature during May 15-June 15 and commercial gill net catch per unit of effort 8 years later. Correlation coefficient was -0.36. The hollow points were predicted from a linear regression.

The model incorporated a von Bertalanffy growth curve which is independent of fishing pressure, fishing rate and population density. Back-calculated lengths were generated with computer programs (Frie 1982) using the Fraser-Lee algorithm with a=2.36in for parameterizing the growth curve. The von Bertalanffy function was fitted to mean back-calculated lengths at age for 299 females ranging in age from 4 to 14 collected in 1983 and 1984. Parameters used were L_∞ = 29.6in, K = 0.132 and T = 0.412 yr. The model user can adjust parameters in the program if growth changes in the future (line 270).

Age-specific mortality rates were applied during each year that individual cohorts were extant since the simulation model was age-structured. Because the fishing season was 10 months in length, the Lake of the Woods walleye fishery was assumed to be Type 2, i.e. fishing and natural mortality operated concurrently (Ricker 1975). Total instantaneous mortality rates (Z) were estimated from length-converted curves (Pauley 1983, 1984) from angling and index gill net catches for 1968-70 and 1981-83. Estimates of Z from standard catch curves were variable and dependent on the gear and range of ages included in the regression (Table 2). A grand mean of Z=0.76 (annual Due to lack of data for ages 13-16, half of the q for age 12 was used as an estimate of catchability.

Exploitation rates (u) for each fishery were interpolated from quadratic least squares functions (Fig. 3) used to describe exploitation rates as a function of size, based on tag returns in 1982. Parameters were divided by the tag reporting rate. If the rate equaled 1.0, then every tag found was reported and the exploitation rates were the lowest possible. Average lengths at each age were estimated from the von Bertalanffy growth function and used to generate age-specific exploitation rates.

Table 2. Instantaneous (Z) and total annual (A) mortality rates for Lake of the Woods, Minnesota, estimated from slopes of conventional catch curves. Length-frequencies were converted to age-frequencies via age-length keys.

Period	Mortality rate Z	A	Ages	Source
		Pound nets		
1939-1943	0.83	0.56	4-10	Carlander 1942
1968-1970	0.91	0.60	4-10	Heyerdahl and
	1.16	0.69	6-9	Smith 1972
June 1982	1.18	0.69	6-8	Present study
		Gill nets		
1968-70	0.80	0.55	4-9	Schupp 1974
1980-1984	1.05	0.65	4-9	Present study
	0.92	0.60	5-7	Present study
	0.75	0.53	4-7	Present study
		Angling		
1968-1970	0.75	0.53	4-9	Schupp 1974
1981-1984	1.01	0.64	4-9	Present study
Mean (all types)	0.76	0.53		

Age-specific catchabilities were multiplied by the probability that a walleye of age i would be creeled after it is caught. The model used an age-length key after length regulations were chosen (Table 3). The user can specify any length as a limit after choosing one of five length-limit options (no size limits, line 1505; maximum size limits, line 1510; minimum size limits, line 1610; slot size limits, line 1710; and window size limits, line 1810).

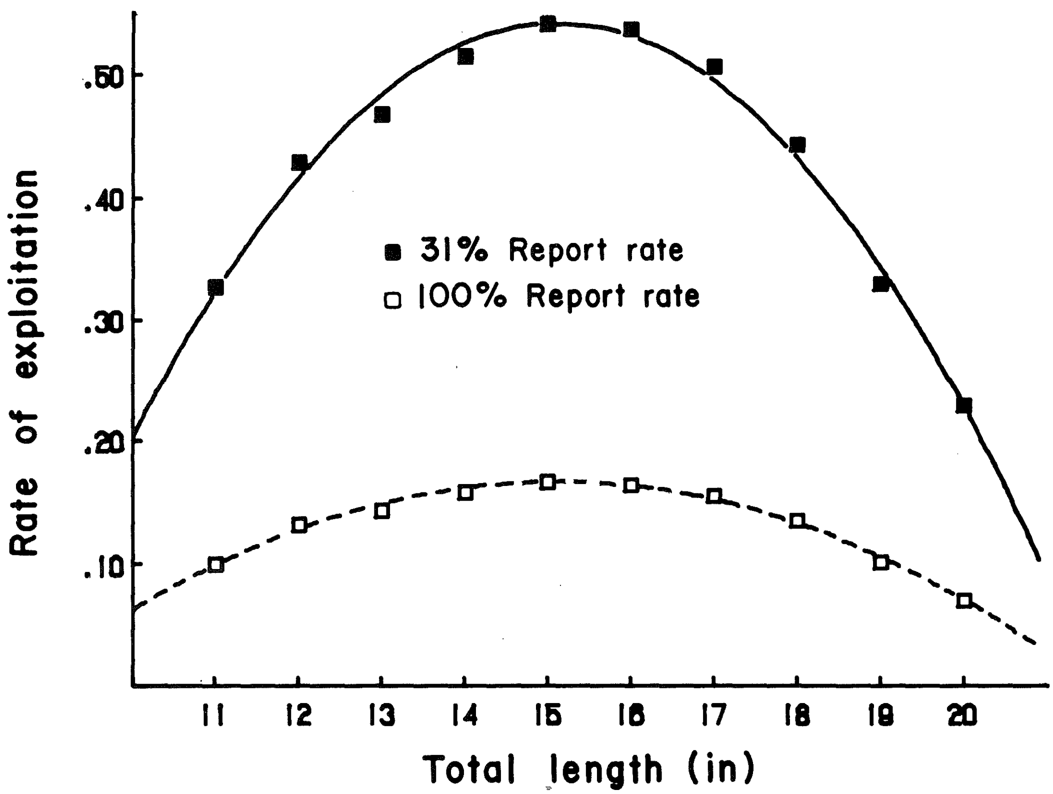


Figure 3. Relationship between length of marked male walleye and the proportion of marked male walleye recaptured (rate of exploitation) for two probabilities of reported marked recaptures, Lake of the Woods, Minnesota.

Table 3. Age-length key for walleye from Lake of the Woods, Minnesota. Percentages for walleye ages 1-11 were from 602 samples from experimental and commercial gill nets during July 1984. Percentages for ages 10-16 were from samples taken from 1980-84.

		Length class (in)																						
Age	No	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	92	7.6	54.3	38.0																				
2	53			7.5	39.6	41.5	11.3																	
3	107					8.4	25.2	41.1	25.2															
4	42							7.1	35.7	45.2	11.9													
5	92								2.2	18.5	40.2	29.3	9.8											
6	91									1.1	7.7	22.0	31.9	24.2	13.2									
7	48										2.1	6.3	33.3	31.3	22.9	4.2								
8	54											3.7	9.3	13.0	24.1	16.7	25.9	7.4						
9	13														23.1	38.5	23.1	15.4						
10	7																25.0	25.0	25.0	25.0				
11	16																			15.0	55.0	15.0	15.0	
12	6																			17.0	33.0	17.0	33.0	
13	6																			40.0	20.0	20.0	20.0	
14	1																					100.0		
15	2																						50.0	50.0
16	2																							100.0
No.	632	7	51	39	21	30	33	47	43	38	52	52	59	45	39	16	20	8	3	7	10	6	5	3

Estimates of historical fishing effort (f) were used to derive instantaneous fishing mortality rates (F=q*f) and for generating historical scenarios for validating the model. Estimates of commercial fishing effort were available for each year from 1949-84 but sport fishing effort had been estimated only for 1968-70 (Schupp 1974). These estimates were used to derive values for other years between 1949 and 1984. Based on an estimated six-fold increase in sport fishing effort on Lake Winnibigoshish between 1939 and 1958 (Osborn 1981), a factor of five was divided into the annual sport fishing effort on Lake of the Woods during 1968-70 to obtain an effort estimate for 1949. A line connecting these two estimates was used to predict effort each year form 1949 to 1970 (Fig. 4). A line connecting the estimates between 1968-70 and 1982-84 similarly predicted fishing effort each year from 1971 to 1984 and was extended for subsequent years. The model assumed no commercial effort after 1984 and an increase in sport fishing effort equal to that from 1970 to 1984 to a constant maximum of 3 million mh/year. The model allowed for season closures based on the proportion of annual angling effort attributed to each two-week fishing period (Table 4).

The model assumed that mean lengths of walleye in the catch and in the creel were dependent on the age-specific sport catchabilities of the 1982 tag returns. Simulated mean sizes in the creel were larger than simulated mean sizes in the catch because only an estimated 30% of age 3 and 50% of age 4 walleye were creeled. These percentages were placed in the form of proportions in two variables (line 300).

Although the only estimates of angler creel rates were from surveys during 1968-70 (Schupp 1974) and 1982-84, gaps in the time series were filled by intuition, i.e. by providing a "best guess" based upon the perceptions of people long associated with the fishery. Since no changes in the walleye

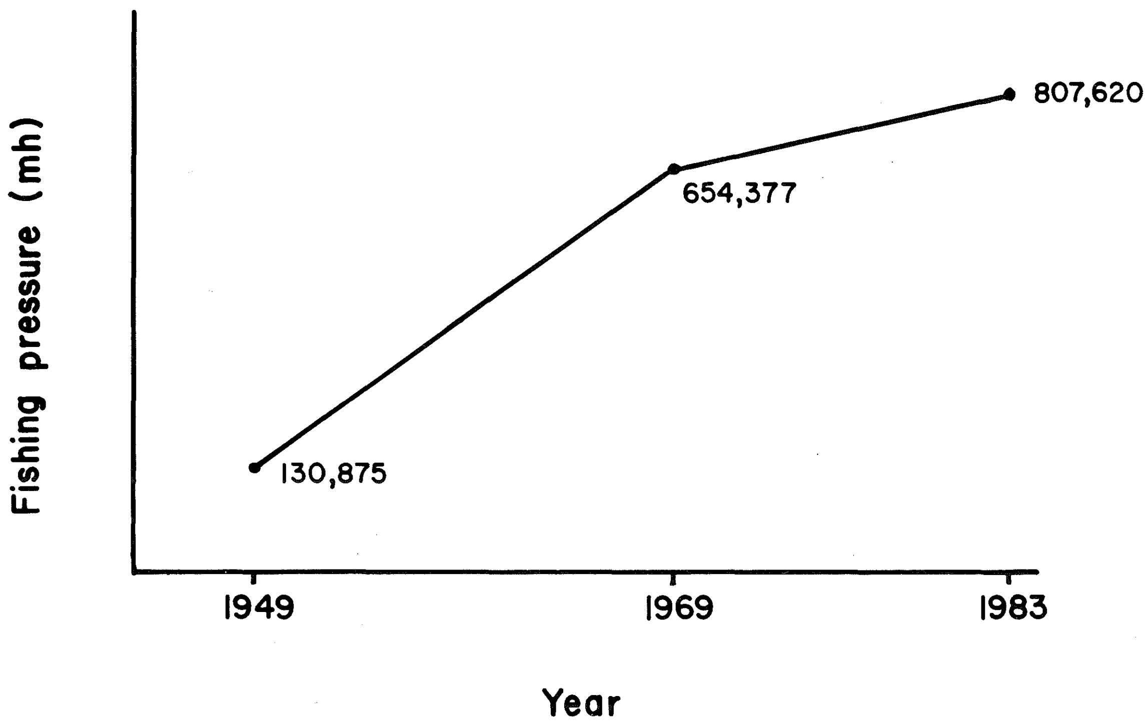


Figure 4. Estimated trend of fishing pressure from three estimates of angler-hours.

Table 4. Distribution of angling effort (mh) during the open-water season of 1984, Lake of the Woods, Minnesota.

Period	Number of manhours	Proportion of season
12-31 May	88,310	0.176
1-15 June	69,450	0.138
16-30 June	97,110	0.193
1-15 July	82,660	0.165
16-31 July	41,210	0.082
1-15 August	43,670	0.087
16-31 August	22,610	0.045
1-15 September	36,110	0.072
16-30 September	7,550	0.015
1-20 October	13,500	0.027
Totals	502,180	1.000

population due to angling were demonstrated in either the present study or that by Schupp (1974), it was assumed that walleye were caught in proportion to their year-class abundance. Angling success could therefore be based on an index of year-class abundance, commercial gill net CPUE. Since catch rates predicted by the model were higher than estimates for recent years, an intuitive trend from 1975-84 using a slowly-declining creel rate as angling pressure increased was assumed. Parameters were estimated from linear regression of creel survey data from 1968-70 (Schupp 1974) and 1982-84.

Functional relationships in the model were tested by a comparison of simulated and historical trends. The historical trends were generally based on real data although general directions of change were sometimes accepted without conclusive empirical data.

RESULTS

Assessment Netting

The composition of the principal species in Lake of the Woods as determined from assessment nets has remained unchanged since 1968-70 (Schupp 1974). Cisco (Coregonus artedii), white sucker (Catostomus commersoni), northern pike (Esox lucius), yellow perch, sauger (Stizostedion canadense) and walleye comprised more than 95% of both July and September catches from 1980-84 (Figs. 5 and 6). The burbot (Lota lota) was the only species of commercial significance not frequently sampled in assessment nets. Percids comprised 72% of the total assessment net catch from 1980-84 compared to 62% in 1968-70. The presence of small numbers of rainbow trout (Salmo gairdneri) in the July 1983 assessment nets resulted from the stocking of approximately 100,000 rainbow trout in May 1983 by the Lake of the Woods Chapter of the Minnesota Border Lake Coalition. This was the only time stocked trout were captured. Comparative summaries of assessment net catches from 1968-70 and 1980-84 are presented for both July and September netting periods in Appendix Tables 1 and 2, respectively.

Total assessment net CPUEs for combined species have declined by both number and weight since 1968-70 (Appendix Tables 1 and 2), due to the absence in the current study of a large year-class of cisco such as that recruiting to the gear in both 1969 and 1970. July CPUEs have declined 14% by number and 20% by weight since 1968-70 while September catches have increased 3% by number and 5% by weight. Average annual CPUEs between 1968-70 and 1980-84 increased for northern pike, white sucker and yellow perch and declined for cisco, sauger and walleye.

Seasonal variations in assessment net catches were apparent but not as marked as in 1968-70 (Schupp 1974). Total number and weight per lift were

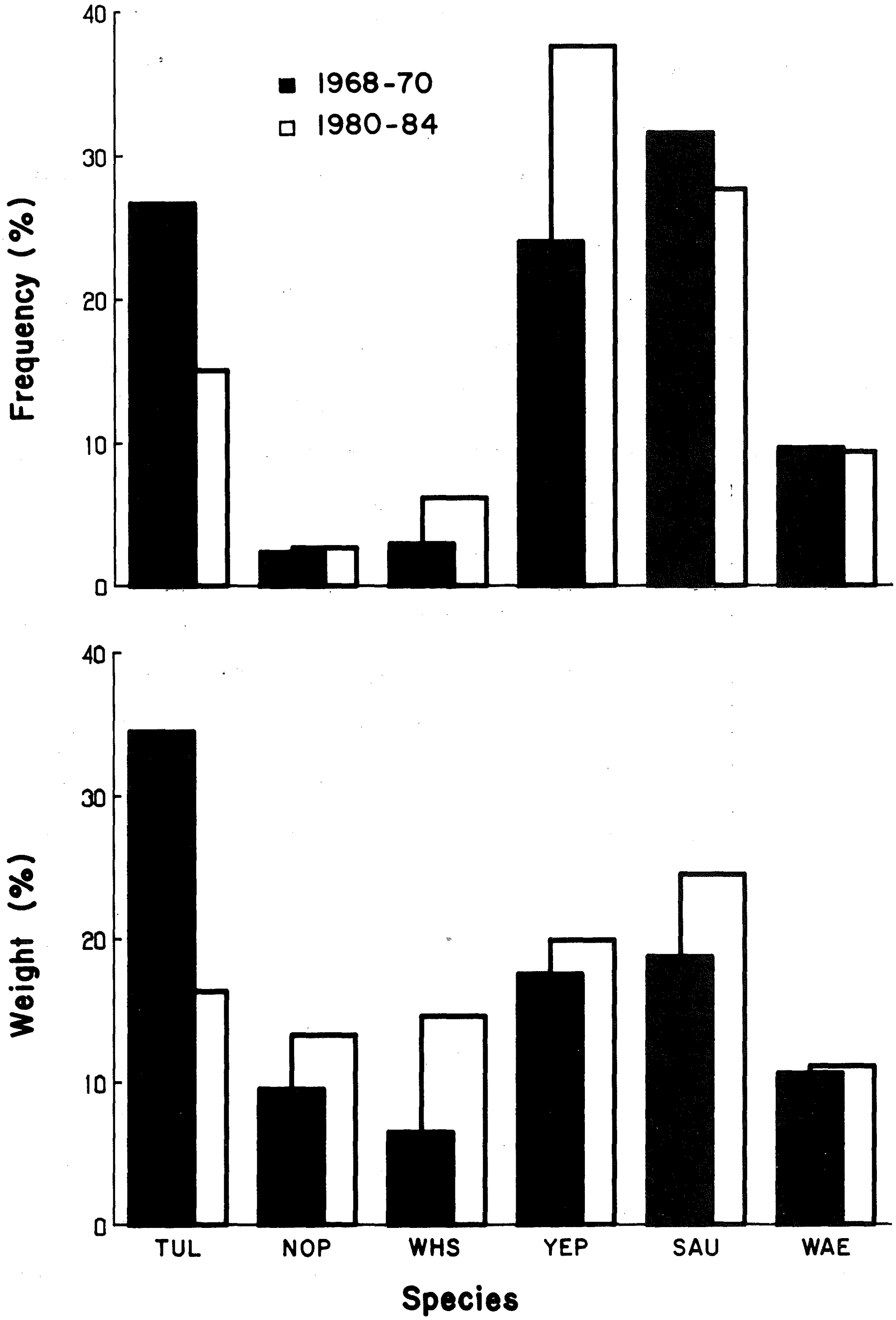


Figure 5. Fish species composition from July assessment netting expressed as percent of total catch by number and weight, Lake of the Woods, Minnesota, 1968-70[a] and 1980-84.

[a] From Schupp (1974).

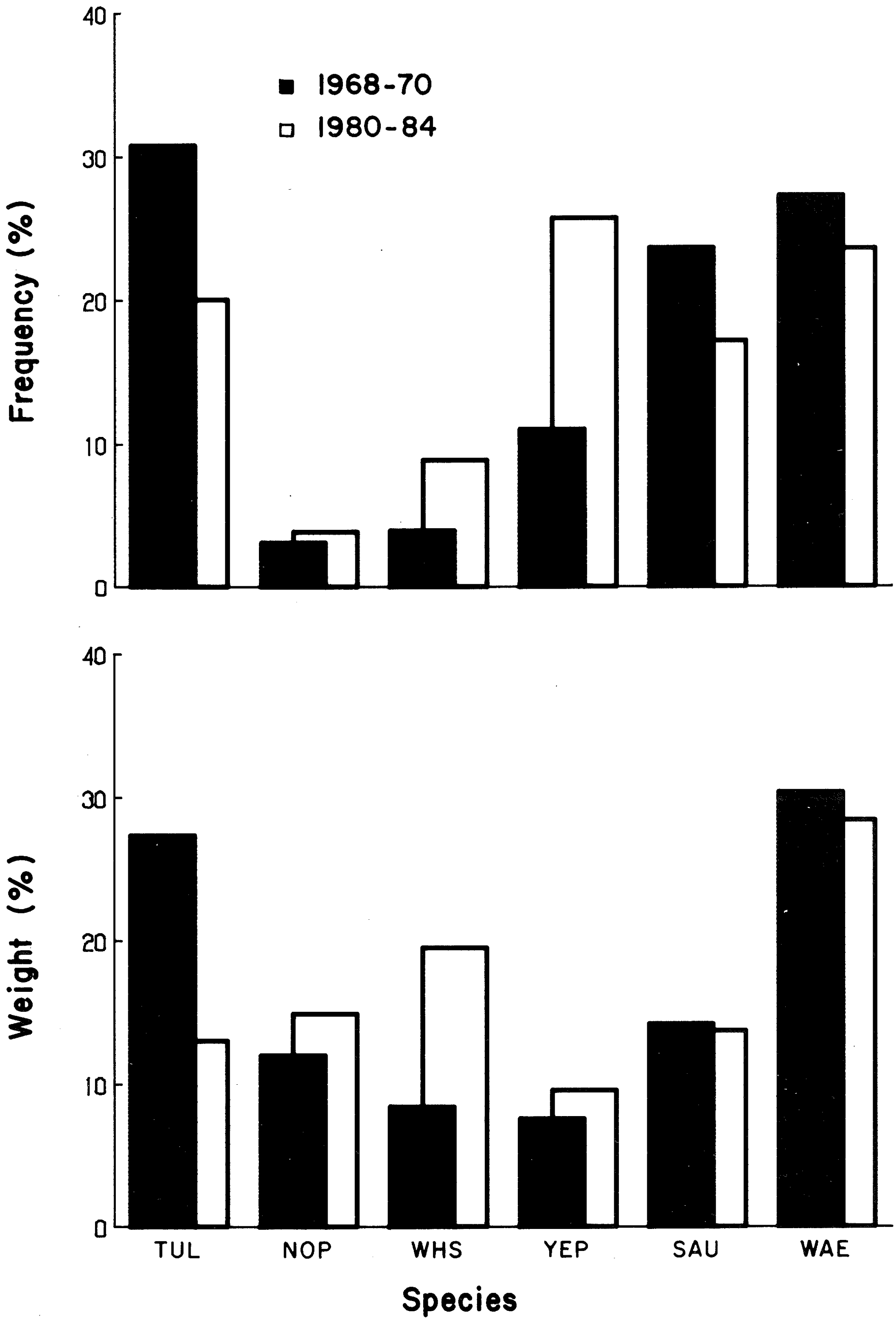


Figure 6. Fish species composition from September assessment netting expressed as percent of total catch by number and weight, Lake of the Woods, Minnesota, 1968-79[a] and 1980-84.

[a] From Schupp (1974).

higher in July than September but only for yellow perch and sauger was this trend observed each year of the study. CPUEs for cisco and northern pike were higher in July in three years and for white sucker in two years of the five years of evaluated netting. September walleye CPUE was higher than that for July in all years except 1982, partially due to continued recruitment to the gear of several strong year-classes and the characteristic inshore movements of walleye in the fall.

Variations in assessment net catches by depth were also evident. Deep-water sets (>20 ft) had the highest catches in both July and September and were dominated by sauger, tullibee, white sucker and yellow perch (Figs. 7 and 8). While the relative contribution of walleye and northern pike to the catch generally increased in shallower sets, they were not as large as those documented by Carlander (1942) and Schupp (1974). Walleye contributed 20% of the catch by number at depths in excess of 20 ft during the September netting period in 1980-84 compared to 8% in similar sets in 1968-70. Catches in sets from other depths were similar to those from 1968-70.

Shoreline seining

Young-of-the-year yellow perch were the most abundant species sampled in 1983-84 shoreline seining, followed by emerald shiners (Notropis atherinoides) and spottail shiners (N. hudsonius). Young-of-the-year smallmouth bass (Micropterus dolomieui), black crappie (Pomoxis nigromaculatus), sauger and walleye constituted the sampled game fish.

Relative abundances of YOY walleye and yellow perch in 1983 and 1984 shoreline seining varied seasonally with the highest abundance occurring from late July to early August (Fig. 9). The percent change in yearly peak abundance was 44% for walleye and 11% for yellow perch. By mid-August, CPUE for YOY walleye had decreased to less than one fish per seine haul.

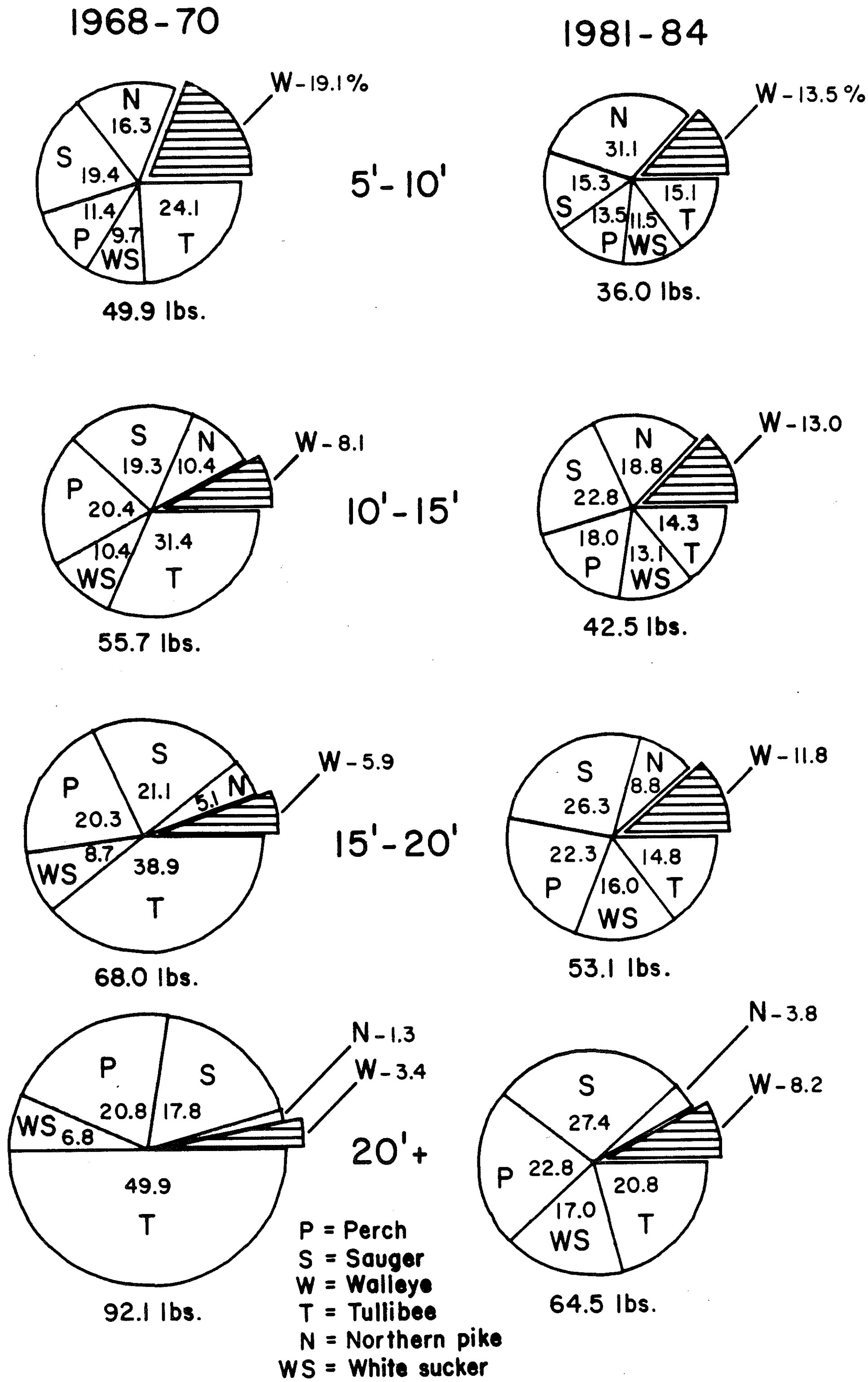


Figure 7. Fish species composition from July assessment netting expressed as mean percentage of total catch by weight (lb) and depth, Lake of the Woods, Minnesota, 1968-70[a] and 1981-84.

[a] From Schupp (1974).

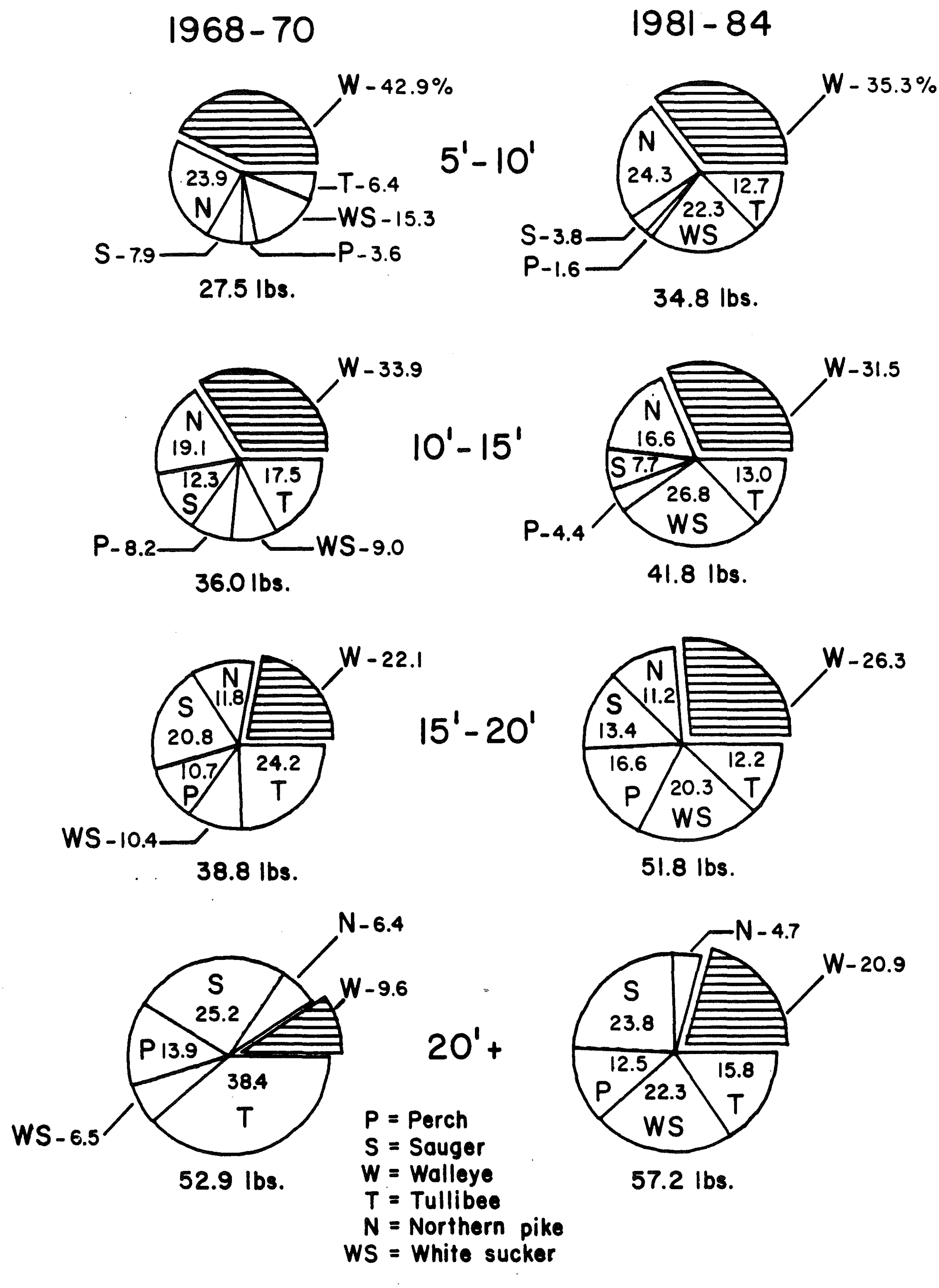


Figure 8. Fish species composition from September assessment netting expressed as mean percentage of total catch by weight (lb) and depth, Lake of the Woods, Minnesota, 1968-70[a] and 1981-84.

[a] From Schupp (1974).

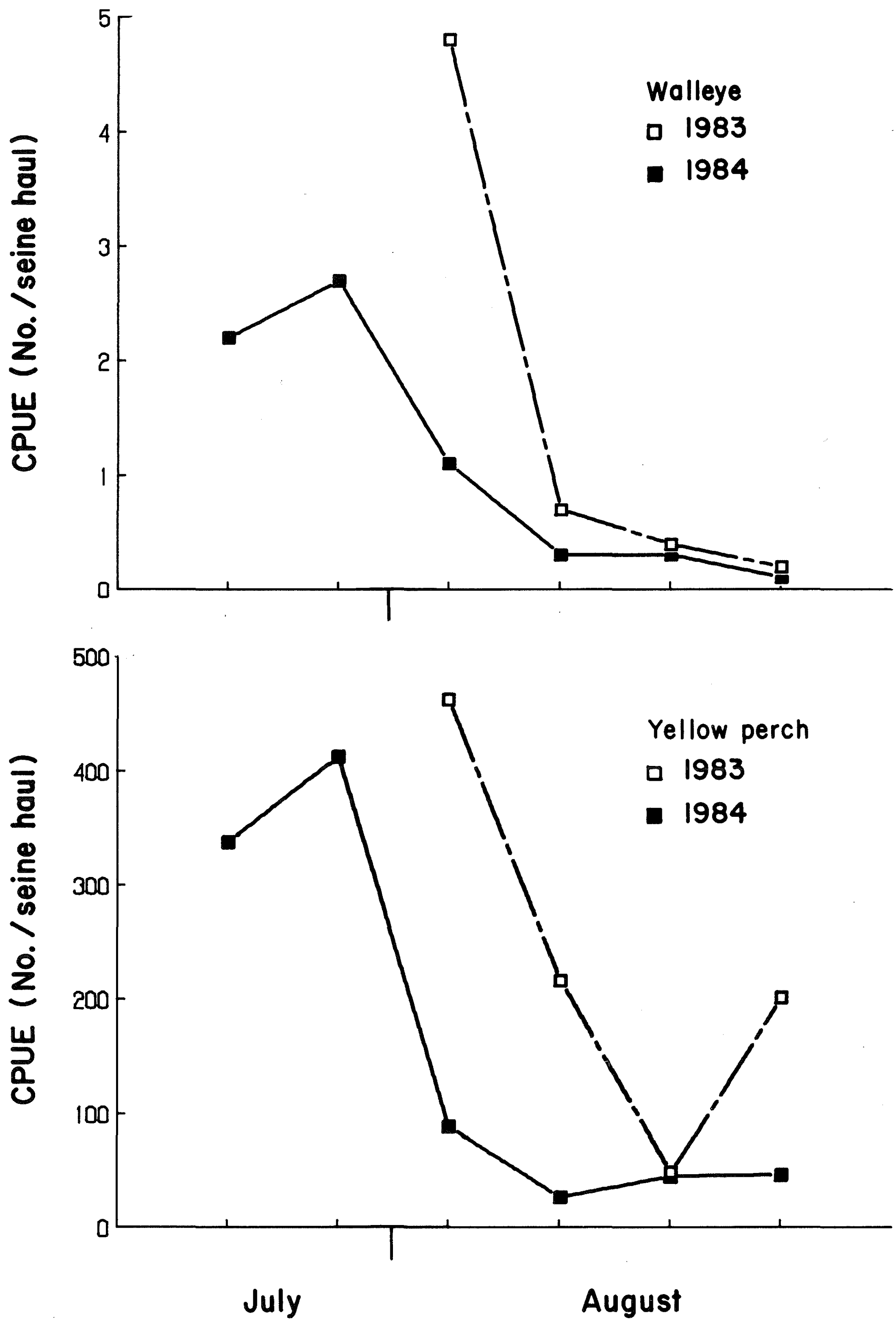


Figure 9. Weekly changes in shoreline seining CPUE for young-of-the-year walleye and yellow perch, Lake of the Woods, Minnesota, j1983 and 1984.

CREEL SURVEY

Open-Water

Average open-water fishing effort from combined catch locations on Lake of the Woods for 1982-84 increased 17% since 1968-70 (Table 5). Lakewide

Table 5. Estimated average annual open-water sportfishing effort by catch location for Lake of the Woods, 1968-70[a] and 1982-84.

	Total boat-trips		Total man-trips		Total manhours	
	1968-70	1982-84	1968-70	1982-84	1968-70	1982-84
Minnesota	32,091	41,314	109,924	127,018	462,217	493,009
Ontario	719	4,787	8,615	16,521	53,644	86,333
Manitoba	600	3,955	4,420	15,964	21,243	93,103
Rainy River	6,165	4,355	19,036	12,993	74,322	42,848
Totals	39,575	54,411	141,995	172,496	611,426	715,292

[a] From Schupp (1974).

effort ranged from 684,173 manhours (mh) in 1983 to 764,169 mh in 1984 and averaged 715,292 mh for the 1982-84 survey period (Appendix Table 3). The largest increases occurred in Canadian waters, 61% in Ontario and 338% in Manitoba. Effort on American waters has remained relatively constant, increasing by approximately 7% in Minnesota while decreasing by 42% on the Rainy River, a net decline for those combined waters of 0.1%. Approximately 69% of the total effort was in Minnesota waters of the lake, 12% in Ontario, 13% in Manitoba and 6% on the Rainy River. Effort for combined catch locations averaged 1.1 mh/A, ranging from 0.3 mh/A in Ontario, 1.6 mh/A in the Minnesota portion of Lake of the Woods, 10.7 mh/A in Manitoba and 2.6 mh/A in the Rainy River. Over 90% of the effort on the Rainy River occurred near the mouth and was probably in the range of 60-70 mh/A. Over 70% of the fishing effort was completed by mid-July of each year (Fig. 10).

Relative effort by chartered launches and small boats/pleasure craft has remained unchanged since 1968-70. Approximately 38% of the total effort (mh) came from small boats, 45% from pleasure craft and 18% from chartered launches for 1982-84, compared to 83% for combined small boats/pleasure craft and 17% for chartered launches reported by Schupp (1974) for 1968-70 (Table 6). Small boats and pleasure craft were not segregated in the 1968-70 survey and data for each were combined for the present study to facilitate comparison.

Total angling CPUEs for combined catch locations averaged 0.47 fish/mh on Lake of the Woods from 1982-84, a decline of 23% since 1968-70 (Table 7). CPUE's for all species have declined by 51% in Manitoba, 28% in Minnesota, 21% in Ontario and 11% on the Rainy River during this period.

The largest portion of the open-water sport harvest, commensurate with pressure, also came from Minnesota waters of Lake of the Woods. Estimated total numbers of fish in the sport catch ranged from 312,261 in 1982 to 357,442 in 1984 (Appendix Tables 4-9) and averaged 335,264 for the 1982-84 survey period (Table 8). Estimated total pounds harvested ranged from 322,522 in 1982 to 396,025 in 1984, averaging 360,486 lbs. Of the estimated total angler catch on Lake of the Woods, 64% by number were harvested from Minnesota waters, 16% from Manitoba, 15% from Ontario and 5% from the Rainy River.

Walleye, sauger, northern pike and yellow perch comprised the major portion of the Lake of the Woods open-water sport catch. These four species

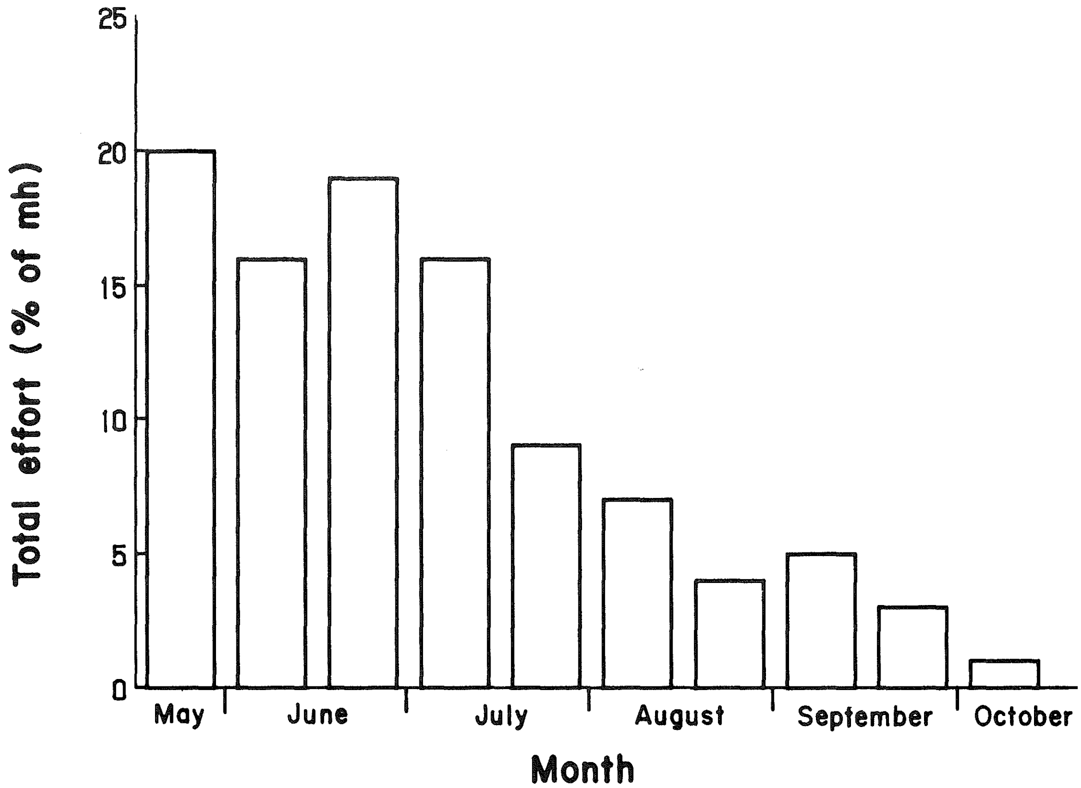


Figure 10. Percent of total annual effort by Minnesota-based anglers by monthly time periods, Lake of the Woods, 1982-84.

Table 6. Relative fishing effort on Lake of the Woods by catch location and fishing craft[a] expressed as total manhours (mh) and percentage of total manhours (%) for 1968-70[b] and 1982-84.

	Minnesota		Ontario		Manitoba		Rainy River		Totals	
	1968-70 mh	1982-84 mh	1968-70 mh	1982-84 mh	1968-70 mh	1982-84 mh	1968-70 mh	1982-84 mh	1968-70 (% effort by craft)	1982-84 (% effort by craft)
Small boats	408,512	232,102	12,093	13,650	9,631	9,794	74,322	15,338	504,558	270,884
(% by location)		(85.7)		(5.0)		(3.6)		(5.7)		(37.9)
Pleasure craft		214,392		41,234		45,978		17,228		318,832
(% by location)		(67.2)		(12.9)		(14.4)		(5.4)		(44.6)
Combined totals	408,512	446,494	12,093	54,884	9,631	55,772	74,322	32,566	504,558	589,716
(% by location)	(81.0)	(75.7)	(2.4)	(9.3)	(1.9)	(9.5)	(14.7)	(5.5)	(82.5)	(82.4)
Chartered launches	53,705	46,514	41,551	31,449	11,612	37,331	------	10,282	106,868	125,576
(% by location)	(50.3)	(37.0)	(38.1)	(25.0)	(10.9)	(29.7)		(8.2)	(17.5)	(17.6)
Totals	462,217	493,008	53,644	86,333	21,243	93,103	74,322	42,848	611,426	715,292

[a] Only combined data for small boats and launches was available for 1968-70.
[b] From Schupp (1974).

Table 7. Average catch per unit effort (CPUE) expressed as fish per manhour (mh) for all fish species from the open-water sport catch, Lake of the Woods, 1968-70[a] and 1982-84.

	Minnesota	Ontario	Manitoba	Rainy River	Totals
1968-70	0.60	0.76	1.18	0.44	0.61
1982-84	0.43	0.60	0.58	0.39	0.47

[a] From Schupp (1974).

Table 8. Estimated average annual open-water sport fishing effort and harvest by catch location, Lake of the Woods, 1982-84.

	Minnesota	Ontario	Manitoba	Rainy River	Totals
Total manhours	493,008	86,333	93,102	42,848	715,292
CPUE (fish/h)	0.43	0.60	0.58	0.39	0.47
Total catch (no)	212,906	51,715	54,134	16,508	335,264
Lake sturgeon	16	0	0	0	16
Mooneye	10	0	0	0	10
Rainbow trout	5	0	0	0	5
Northern pike	6,652	992	580	2,594	10,819
Bullhead	9	0	0	0	9
Burbot	5	0	0	0	5
Rock bass	39	0	0	32	71
Smallmouth bass	154	128	0	175	457
Yellow perch	7,346	1,417	758	640	10,162
Sauger	25,749	3,181	2,506	1,085	32,521
Walleye	172,921	45,996	50,290	11,982	281,189
Total catch (lb)	225,446	56,810	56,556	21,674	360,486
Lake sturgeon	347	0	0	0	347
Mooneye	10	0	0	0	10
Rainbow trout	4	0	0	0	4
Northern pike	18,215	2,731	1,983	6,424	29,353
Bullhead	9	0	0	0	9
Burbot	11	0	0	0	11
Rock bass	29	0	0	24	53
Smallmouth bass	219	194	0	270	684
Yellow perch	3,932	833	543	371	5,679
Sauger	16,499	2,160	1,692	725	21,076
Walleye	186,171	50,892	52,338	13,860	303,262

constituted 99.8% by number and 99.7% by weight of the catch (Table 9). An estimated 16 rainbow trout were harvested in 1983 and none in 1984.

Catch rates for walleye continued to be higher in Canadian waters of the lake during the 1982-84 survey period. Walleye angling success was higher in both Ontario (0.53/mh) and Manitoba (0.54/mh) than in Minnesota (0.35/mh) and the Rainy River (0.28/mh) (Table 9). CPUE averaged 0.39/mh for combined catch locations and have declined by 22% since 1968-70 (Table 10). Declines in walleye CPUE were greatest in Manitoba (49%), followed by Minnesota (27%), Ontario (20%) and the Rainy River (15%). The only increase in CPUE for any catch location since 1968-70 was for small boats/pleasure craft fishing in Ontario waters (20%). The catch rate from chartered launches was 20% higher than for small boats/pleasure craft in 1982-84, compared to being 50% higher in 1968-70.

Walleye have continued to dominate the Lake of the Woods sport harvest. Walleye comprised 84% by both number and weight of the average annual sport catch from 1982-84, compared to 81% and 83% by number and weight, respectively, for 1968-70 (Schupp 1974). Total estimated numbers of walleye in the open-water sport harvest ranged from 262,379 in 1982 to 305,079 in 1984 (Appendix Tables 4-6) and averaged 281,189 for the 1982-84 survey period, a decline of 7% since 1968-70 (Table 9). The walleye catch has declined by 22% and 51% for Minnesota waters and the Rainy River, respectively, and increased by 29% in Ontario and 125% in Manitoba since 1968-70. Total weight of walleye harvested from combined catch locations ranged from 266,297 lb in 1982 to 339,890 lb in 1984, averaging 303,262 lb from 1982-84, a 15% decline since 1968-70 (Table 9). Minnesota waters produced 186,171 lb of walleye, a decline of 28% by weight and 22% by number since 1968-70 (Schupp 1974). Mean weight of walleye in the sport catch

Table 9. Average annual sport fishing harvest estimates and mean weights by catch location for northern pike, yellow perch, sauger and walleye from Lake of the Woods, 1968-70[a] and 1982-84.

	Minnesota		Ontario		Manitoba		Rainy River		Totals	
	1968-70	1982-84	1968-70	1982-84	1968-70	1982-84	1968-70	1982-84	1968-70	1982-84
Total manhours	462,217	493,009	53,644	86,333	21,243	93,103	74,322	42,848	611,426	715,292
Total catch (no)	277,295	212,668	40,804	51,586	25,099	54,134	32,317	16,301	375,515	334,689
Northern pike	8,294	6,652	307	992	167	580	1,967	2,594	10,735	10,819
Yellow perch	10,157	7,346	849	1,417	830	758	633	640	12,469	10,162
Sauger	38,204	25,749	4,026	3,181	1,733	2,506	5,437	1,085	49,400	32,521
Walleye	220,640	172,921	35,622	45,996	22,369	50,290	24,280	11,982	302,911	281,189
Total catch (lb)	319,108	221,124	49,671	56,616	25,528	56,556	32,983	21,380	427,290	359,369
Northern pike	23,731	18,215	826	2,731	466	1,983	3,632	6,424	28,655	29,353
Yellow perch	7,153	3,932	595	833	639	543	395	371	8,782	5,679
Sauger	30,077	16,499	3,187	2,160	1,377	1,692	3,426	725	38,067	21,076
Walleye	258,147	186,171	45,063	50,892	26,046	52,338	25,530	13,860	354,786	303,262
Mean weight (lb)	1.15	1.04	1.22	1.10	1.02	1.05	1.02	1.31	1.14	1.06
Northern pike	2.86	2.74	2.69	2.75	2.79	3.42	1.85	2.48	2.67	2.71
Yellow perch	0.70	0.54	0.70	0.59	0.77	0.72	0.62	0.58	0.70	0.56
Sauger	0.79	0.64	0.79	0.68	0.80	0.68	0.63	0.67	0.77	0.65
Walleye	1.17	1.08	1.27	1.11	1.16	1.04	1.05	1.16	1.17	1.08
CPUE (fish/mh)	0.600	0.431	0.761	0.598	1.182	0.581	0.435	0.380	0.614	0.468
Northern pike	0.018	0.013	0.006	0.011	0.008	0.006	0.026	0.061	0.018	0.015
Yellow perch	0.022	0.015	0.016	0.016	0.039	0.008	0.009	0.015	0.020	0.014
Sauger	0.083	0.052	0.075	0.037	0.082	0.027	0.073	0.025	0.081	0.050
Walleye	0.477	0.351	0.664	0.533	1.053	0.540	0.327	0.280	0.495	0.393

[a] From Schupp (1974).

Table 10. Comparison of average catch rates from small boats/pleasure craft and chartered launches expressed as fish caught per manhour (mh) for Lake of the Woods walleye from 1968-70[a] and 1982-84.

	Boats[b]		Chartered launches		Totals	
	1968-70	1982-84	1968-70	1982-84	1968-70	1982-84
Minnesota	0.45	0.35	0.67	0.40	0.48	0.35
Ontario	0.49	0.59	0.72	0.44	0.66	0.53
Manitoba	1.28	0.51	0.86	0.59	1.05	0.54
Rainy River	0.33	0.27	----	0.30	0.33	0.28
Totals	0.45	0.38	0.71	0.46	0.50	0.39

[a] From Schupp (1974).
[b] Small boats and pleasure craft are combined to facilitate comparisons between 1968-70 and 1982-84.

averaged 1.08 lb in 1982-84, compared to 1.17 lb in 1968-70, decreasing at all catch locations except the Rainy River, where the average weight increased by 11%.

Entries at a local bait shop for walleye over 5 lb increased from 146 for the 3-year period from 1968-70 to 152 in 1981. Each year from 1982-84 walleye larger than 10 lb were recorded, whereas from 1968-70 the largest recorded weighed 6 lb.

The walleye catch followed a typical pattern of good early season fishing declining by mid-July through the remainder of the summer and increasing again to the highest annual levels in the fall when effort was the lowest (Fig. 11). The mid-summer peak depicted for 1968-70 reflects the substantial influence recruitment of the 1966 year-class had on the sport fishery in 1970 (Schupp 1974).

The harvest of sauger, yellow perch and northern pike was generally incidental to that for walleye. CPUEs for combined catch locations declined

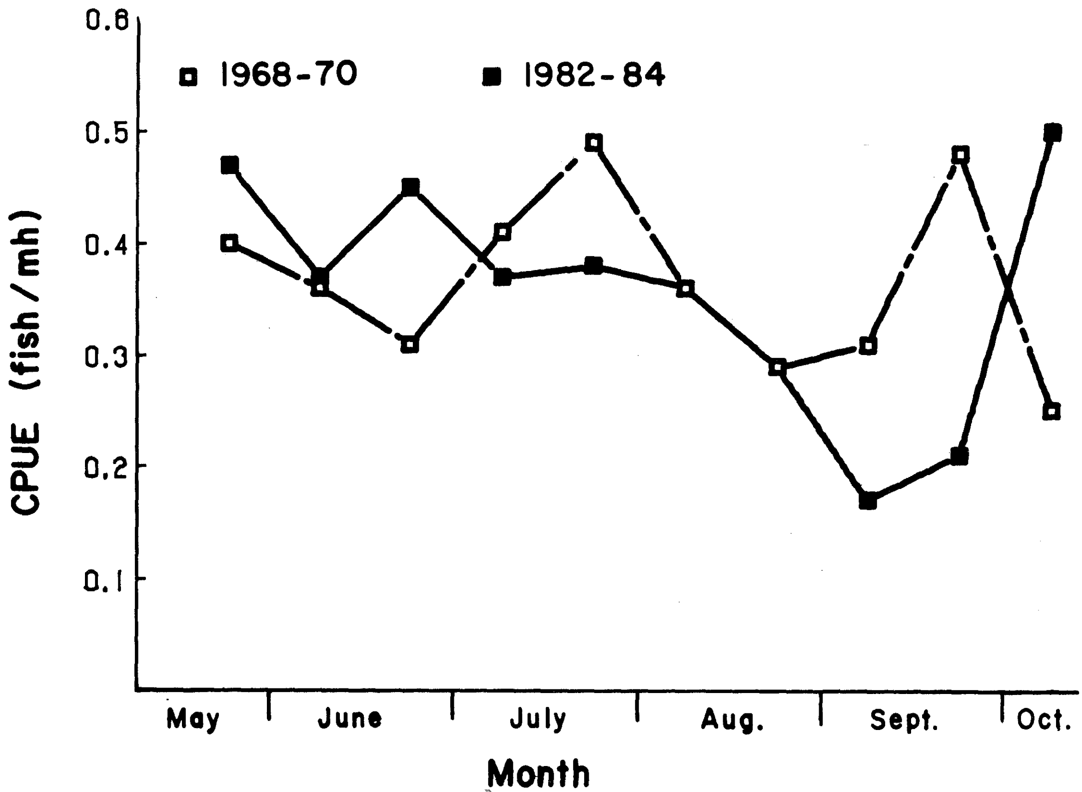


Figure 11. Average CPUE expressed as catch per manhour by month, Lake of the Woods, 1968-70[a] and 1982-84. The mid-summer peak in 1968-70 reflects the influence of the 1966 year-class recruiting in 1970.

[a] From Schupp (1974).

for both sauger (38%) and yellow perch (30%) since 1968-70 (Table 9). Total numbers harvested also declined for sauger (34%) and yellow perch (19%) as did mean weights (16% and 20% for sauger and yellow perch, respectively). CPUE, harvest and mean weight of northern pike were relatively constant over the same time period.

The open-water walleye sport harvest consisted primarily (84%) of age 3-6 fish ranging in size from 12 to 17in TL (Fig. 12). Approximately 86% of the 1982-84 sport catch were less than age 5. Schupp (1974) reported that 68% of the 1968-70 sport catch was comprised of age 4-6 walleye and that 45% of the catch were less than age 5.

The catch of walleye $\geq$ 16in TL remained relatively constant from May through August (Fig. 13). Even though fishing pressure was declining, September and October showed a considerable decline as would be expected from the decline in fishing pressure.

Winter

Winter fishing effort along the south shore of Lake of the Woods in 1982-83 has dramatically increased from average winter effort in 1967-70. Total winter effort was estimated as 401,467 mh, an increase of 835% since 1968-70 (Table 11). Winter effort in the present study constituted 36% of the total annual sport effort on Lake of the Woods compared to only 7% in 1967-70 (Tables 5 and 11).

The winter harvest from Lake of the Woods was comprised primarily of sauger, walleye, yellow perch, northern pike and burbot. Data on winter harvest of northern pike, yellow perch and burbot were not collected in 1982-83. In contrast to open-water and winter fishing in 1967-70, ice fishermen actively sought sauger in addition to walleye in 1982-83. Approximately 11% of the sport walleye harvest, 89% of the sauger harvest

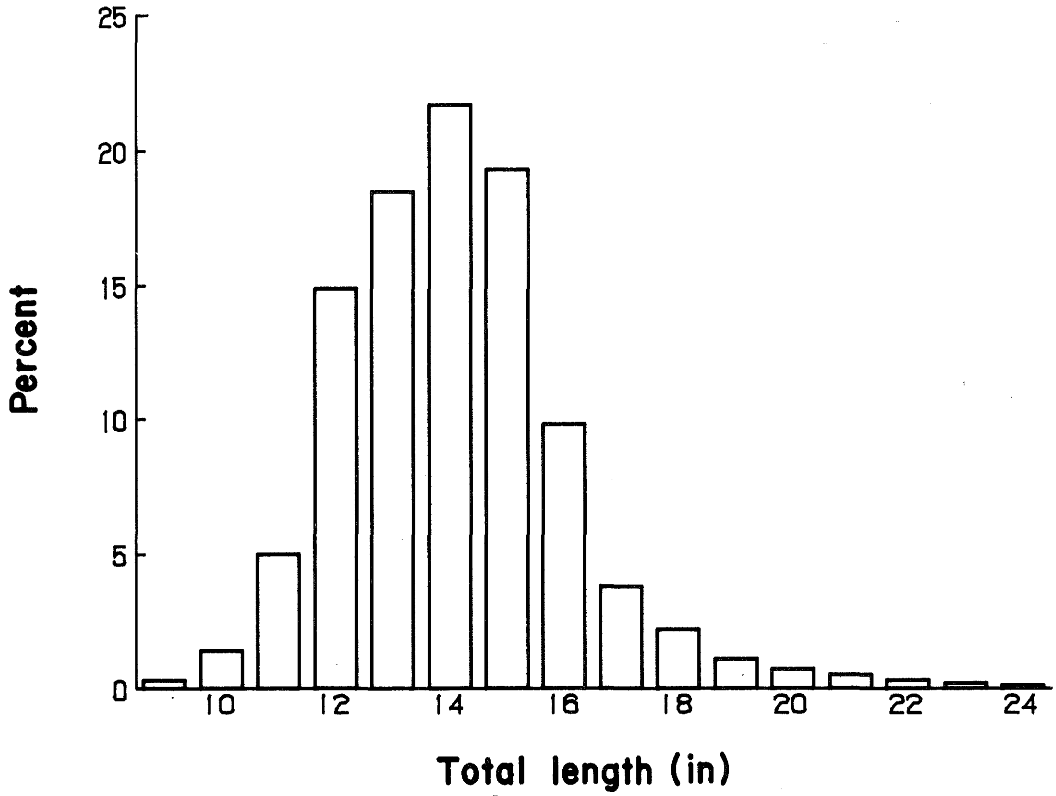


Figure 12. Length-frequency of harvested walleye during the open-water sport fishery, Lake of the Woods, 1983-84.

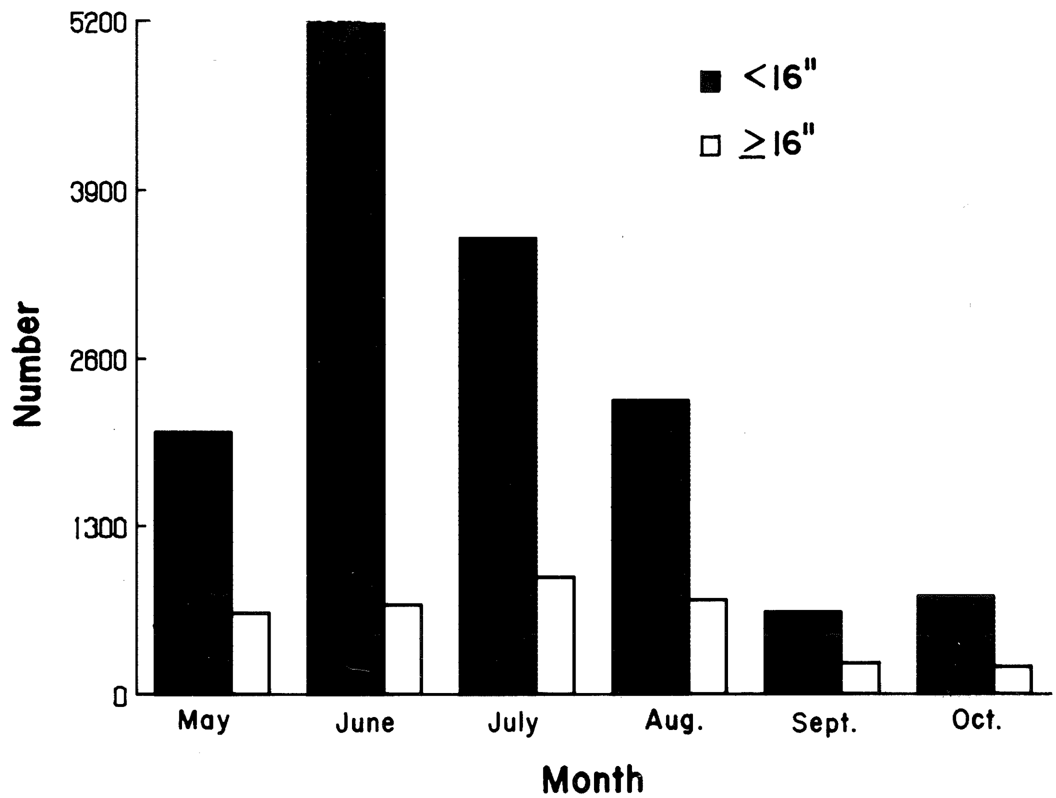


Figure 13. Average total length of walleye caught in the open-water sport fishery, Lake of the Woods, 1982-84.

Table 11. Estimated effort (mh), harvest (lb) and catch rates (CPUE) for the winter fishery, Lake of the Woods, Minnesota, 1967-70[a] and 1982-83.

	1967-70	1982-83
Total mh	42,951	401,467
Total catch (no)		
Walleye	4,198	41,843
Sauger	2,742	277,205
Total catch (lb)		
Walleye	4,040	35,985
Sauger	1,678	163,551
CPUE (fish/mh)		
Walleye	0.10	0.11
Sauger	0.06	0.68
Mean weight (lb)		
Walleye	0.96	0.86
Sauger	0.61	0.59

[a] From Schupp (1974).

and 38% of walleye and sauger combined came from the winter fishery.

Winter sauger CPUE increased by 871% in 1982-83 compared to average winter CPUE from 1967-70 (Table 11). The winter sauger harvest was 277,205 fish weighing 163,550 lb, a 100-fold increase since 1967-70. Average weight of sauger harvested has declined by 3% since 1967-70.

Winter CPUE of walleye in 1982-83 was similar to that for 1967-70 (Table 11). A 10-fold increase in both number and weight of harvested walleye occurred since 1967-70, commensurate with the increase in pressure. The 1982-83 winter walleye harvest increased 897% by number and 791% by weight since 1967-70 (Schupp 1974) while the mean individual weight declined by 12%.

Length-frequency distributions for sauger and walleye from the winter fisheries indicate that the mode in 1982-83 was approximately 1.0in smaller for both species than in 1967-70. A greater percentage of larger walleye ($\geq$16in) were, however, harvested in 1982-83 (Fig. 14) than in 1967-70.

Increases in effort since 1967-70 are substantially greater when the winter fishery is considered. Total annual sport effort by Minnesota-based anglers on Lake of the Woods was estimated to be 1,116,759 mh from 1982-84, an increase of 71% since 1967-70 (Schupp 1974). Considering that the 8-fold increase in winter effort occurred almost exclusively in Minnesota waters of the lake, total effort in Minnesota has increased by 77% over the past 15 years. During the current study, 45% of the annual sport effort in Minnesota waters was provided by the winter fishery compared to 9% in 1967-70 (Schupp 1974).

Total walleye harvest by Minnesota commercial fishermen and Minnesota-based anglers averaged 453,924 lb per year from 1982-84, an increase of 12% since 1967-70 (Table 12). Anglers harvested 67% of the walleye catch by weight during the present study compared to 79% in 1967-70 (Schupp 1974). The commercial harvest of walleye has almost doubled over the past 15 years, substantiating the two-fold increase in commercially legal walleye observed in gill net assessments.

Walleye Population Dynamics

Walleye reproduction has stabilized at relatively high levels in recent years as evidenced by the development of at least 5 strong year-classes since 1976 (1983, 1981, 1979, 1978 and 1976). September assessment netting indicates that the 1982 year-class may also be strong (Table 13).

ANOVA of walleye CPUE from assessment nets indicated that the interactions of Year * Month * Depth and of Year * Month were significant ($p < .05$), while the Year * Depth interaction was only marginally significant

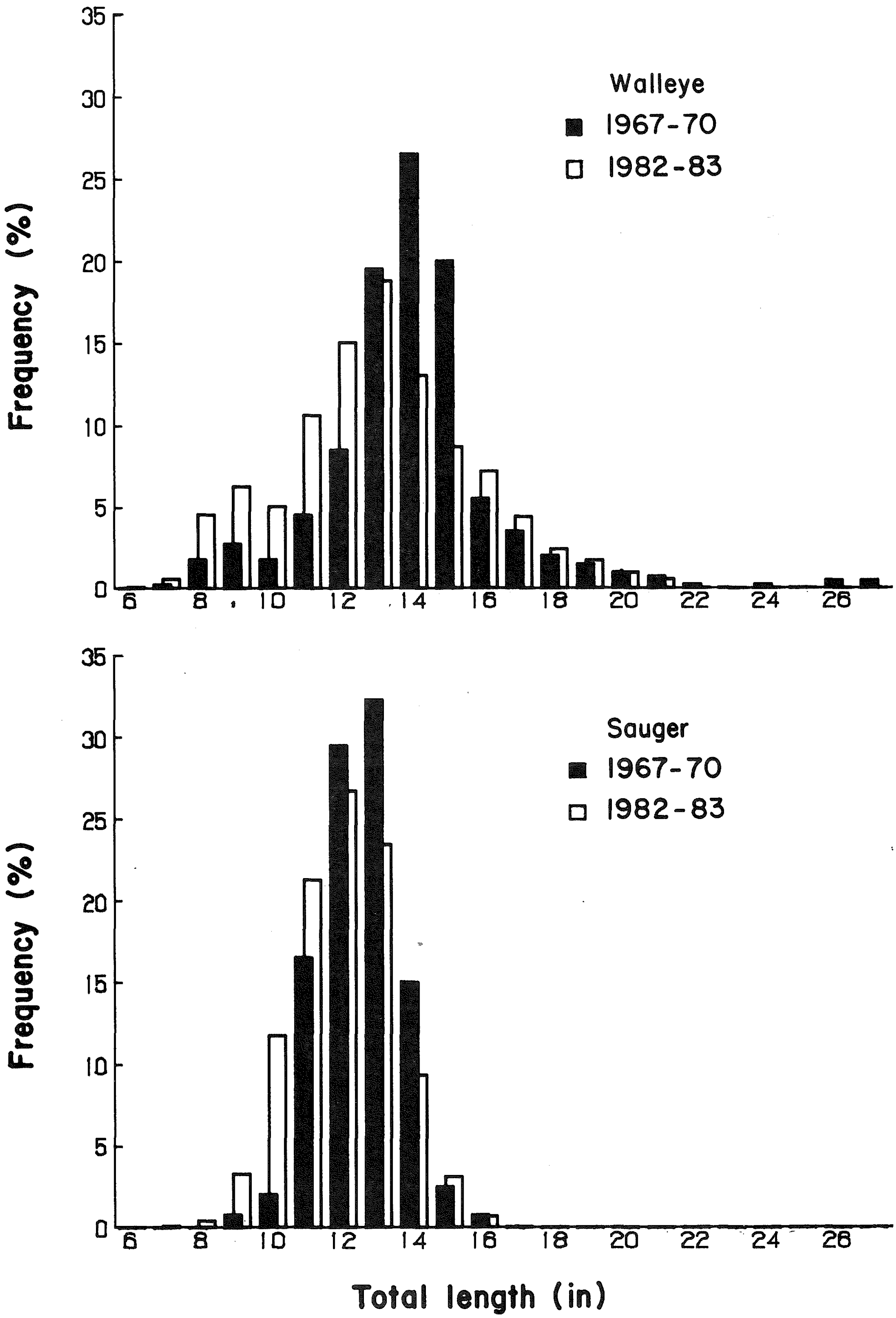


Figure 14. Length-frequency of harvested walleye and sauger during the winter sport fishery, Lake of the Woods, Minnesota, 1967-70[a] and 1982-83.

[a] From Schupp (1974).

Table 12. U. S. commercial and estimated open-water sport walleye harvest in Lake of the Woods, 1968-70[a] and 1982-84.

Year	Sport	Commercial	Total
1968	471,677	105,422	577,099
1969	276,841	79,086	355,927
1970	315,841	100,785	416,626
TOTAL	1,064,359	285,293	1,349,652
1982	266,927	157,074	424,001
1983	302,968	184,975	487,943
1984	339,890	160,261	500,151
TOTAL	909,785	502,310	1,412,095

[a] From Schupp (1974).

(p = 0.0693, Table 14). Scheffe's linear contrast was used to compare the 1968-70 CPUEs with those from 1981-84 individually for months (Year * Month interaction) and for depths (Year * Depth interaction). In both cases, all F tests were non-significant (Table 15). These results indicate that no differences in abundance of walleye were detected in assessment nets between the periods 1968-70 and 1981-84.

Since there were significant differences between Years, Months and Year * Months (Table 14), comparison of all means was performed using Tukey's HSD (Honest Significant Difference). It appears from these comparisons that gill net CPUEs have been highly influenced by a stronger phenomenon such as variation in year-class strength which masks the ability to detect long-term trends. The means in Table 16 are arranged in increasing order. Considering that walleye in Lake of the Woods show peak recruitment (i.e. maximum gear selectivity) to the experimental gill nets at age 4, it is not surprising

Table 13. Year-class distribution of walleye from experimental gill nets, expressed as total number and percentage of catch, Lake of the Woods, Minnesota, 1968-70[a] and 1980-84.

Netting period	No lifts	Total no and % of walleye	Year-class											
			1970	1969	1968	1967	1966	1965	1964	1963	1962	1961	1960	1959
1968-70														
July 1968	40	%				1.2	57.6	0.6	14.5	20.3	3.3	1.2	0.6	0.6
		330				4	190	2	48	67	11	4	2	2
Sept 1968	36	%				0.9	70.7	0.9	10.8	12.0	2.3	0.3	1.4	0.9
		351				3	248	3	38	42	8	1	5	3
July 1969	52	%				1.3	86.4	0.2	5.9	4.7	0.6	0.6	0.2	
		472				6	408	1	28	22	3	3	1	
Sept 1969	43	%		0.5	1.1	2.0	81.0	2.5	3.7	4.7	2.0	1.8	0.3	0.5
		653		3	7	13	529	16	24	31	13	12	2	3
July 1970	40	%		3.6	1.5	1.9	85.9	1.0	3.2	1.7	0.5	0.7		
		412		15	6	8	354	4	13	7	2	3		
Sept 1970	20	%	0.9	6.5	1.8	2.5	76.0	1.1	5.5	4.0	1.0	0.6	0.1	
		816	7	53	15	20	620	9	45	33	8	5	1	
1980-84			1983	1982	1981	1980	1979	1978	1977	1976	1975	1974	1973	1972
July 1980	45	%					9.8	26.4	9.5	32.3	10.0	11.0	1.5	
		409					40	108	39	132	41	45	6	
Sept 1980	36	%					12.1	22.8	11.5	35.5	8.5	6.3	3.1	0.4
		836					101	191	96	297	71	53	26	3
July 1981	52	%				6.5	18.5	37.3	11.3	18.0	4.3	4.5		
		400				26	74	149	45	72	17	18		
Sept 1981	48	%			8.4	6.3	16.3	29.8	11.5	18.4	6.9	2.3		0.3
		729			61	46	119	217	84	134	50	17		2
July 1982	51	%				15.1	31.5	35.1	9.3	7.1	2.2			
		410				62	129	144	38	29	9			
Sept 1982	52	%					37.6	36.8	17.8	7.4		0.4		
		242					91	89	43	18		1		
July 1983	52	%		1.3	28.6	11.2	24.6	18.8	3.6		0.4	2.7		
		224		3	64	25	55	42	8		1	6		
Sept 1983	52	%	15.7	17.0	14.7	16.0	17.7	12.5	2.0	3.2	1.0	0.1		
		694	109	118	102	111	123	87	14	22	7	1		
July 1984	52	%	24.2	11.5	31.3	10.3	13.9	6.0	2.4	0.6	0.4			
		496	120	57	155	51	69	30	12	3	2			
Sept 1984	52	%	28.6	17.2	22.2	10.1	14.4	4.6	1.7	0.8	0.3	0.1		
		1,049	300	180	233	106	151	48	18	8	3	1		

[a] From Schupp (1974).

Table 14. ANOVA table for $\log_{10}$ assessment net walleye CPUEs, Lake of the Woods, Minnesota. The 3-way interaction term (A*B*C) was used for error.

Source	DF	SS	MS	F	P
YEAR (A)	6	6.9639E-01	1.1606E-01	11.88	0.0000
MONTH (B)	1	8.6964E-01	8.6964E-01	89.01	0.0000
DEPTH (C)	3	1.4090E-01	4.6967E-02	4.81	0.0125
A*B	6	6.0695E-01	1.0116E-01	10.35	0.0001
A*C	18	3.5955E-01	1.9975E-02	2.04	0.0693
B*C	3	4.3320E-02	1.4440E-02	1.48	0.2541
A*B*C	18	1.7586E-01	9.7701E-03		
Total	55	2.8926			
Grand average	1	56.7690			

Table 15. Scheffe's linear contrast to compare $\log_{10}$ walleye assessment gill net CPUEs between the time periods 1968-70 and 1981-84 for both the YEAR*MONTH and YEAR*DEPTH interactions, Lake of the Woods, Minnesota.

Interaction term	Contrast	SS (contrast)	Scheffe's F	P
Month				
July	0.653	0.0203	0.35	0.9025
September	0.934	0.0416	0.71	0.6465
Depth				
5-10 ft	2.991	0.2130	1.21	0.3444
>10-15 ft	1.472	0.0516	0.29	0.9937
>15-20 ft	-0.239	0.0014	0.01	1.0000
>20 ft	-1.048	0.0261	0.15	0.9999

Table 16. Comparison of mean walleye assessment gill net CPUE (pooled over depth) using Tukey's HSD (5% level of significance) for Lake of the Woods, Minnesota, from the periods 1968-70[a] and 1981-84. Comparing means for months involved 14 treatments (Year*Month) and the standard error of an average was 0.006989. Pooling over months involved 7 treatments (Year) and the standard error of an average was 0.003495. In both cases the 3-way interaction (Year*Month*Depth) with 18 degrees of freedom was used as the error term in computing the standard error of an average. Yearly means united by underlining constitute homogeneous subsets. The honest-significant-difference for Year*Month was 0.2683615 and for Year only was 0.1632005.

Multiple comparison		Year / Log_{10} CPUE						
Year*Month	July	1983	1981	1968	1969	1970	1982	1984
		0.618	0.866	0.868	0.916	0.957	0.969	0.983
	Sept	1982	1968	1983	1969	1981	1984	1970
		0.800	0.980	1.122	1.159	1.182	1.289	1.395
Year		1983	1982	1968	1981	1969	1984	1970
		0.870	0.884	0.923	1.024	1.035	1.136	1.176

[a] From Schupp 1974.

that the 1970 year-class had the highest $\log_{10}$ CPUE for September. The September assessment net catches may therefore be used to index year-class strength.

Length frequency data indicated that more than twice as many walleye ≥16in TL were present in 1980-84 than in 1968-70. This increase was significant for both July and September (X^2 = 61.9 and 154.8, respectively).

The number of walleye $\geq$16in was also significantly greater in September than July (X^2 = 25.2 and 98.9, respectively) for both the 1968-70 and 1980-84 study periods.

Sex ratios of captured walleye in the 1982 spring tagging operations were similar to those observed in most Minnesota spawning runs. Male to female ratios ranged from 2.5:1 at Four Mile Bay to 6.1:1 at Birchdale for the 10,970 walleye examined at the four tagging locations. Mean sex ratio for combined tagging locations was 4.1:1 (Table 17).

Both males and females entered commercial gill net catch at age 5 and were completely vulnerable to the gear by age 6. The larger walleye in the commercial gear were almost all female due to slower growth by males upon maturity. A number of investigations have revealed that the percentage of females in commercial catches increases with age, generally by the fourth or fifth year (Carlander 1945; Hile 1954; Van Oosten and Deason 1957; Armstrong 1961). Carlander examined 296 walleye from commercial gear in 1941 and determined that females represented 43% of age 4, 47% of age 5, 61% of age 6 and 100% of age 7 walleye. Female dominance in commercial gear was also evident during 1983 and 1984 for 978 walleye examined for sexual development.

No changes in age and size at sexual maturity were apparent when compared to walleye examined by Carlander (1942) in 1941. Mature male walleye ranged from 12.4 to 22.4in TL, averaging 15.7in, while mature females ranged from 12.8 to 24.3in, averaging 17.0in. Male walleye first became sexually mature at age 3 and all were mature by age 6. Females first became sexually mature at age 3 and all were mature by age 7.

Growth rates of female and male walleye were similar to those calculated by both Carlander (1942) and Schupp (1974). Back-calculated lengths of 266 female and 299 male walleye in age groups 1 to 7 were estimated from fish

Table 17. Age and sex structure of walleye at four tagging locations on Lake of the Woods, Minnesota, 1982.

Tagging location	Male	Female	Unknown	Totals
Birchdale (Rainy River)				
Number	2,551	415	32	2,998
Mean length (in)	16.0	20.1		
Mean age (yr)	6	8		
Sex ratio	6.1:	1.0		
Four Mile Bay				
Number	945	372	23	1,340
Mean length (in)	15.1	18.1		
Mean age (yr)	6	7		
Sex ratio	2.5:	1.0		
Elm Point				
Number	2,642	617	237	3,496
Mean length (in)	15.1	18.5		
Mean Age (yr)	6	7		
Sex ratio	3.1:	1.0		
Flag Island				
Number	1,161	369	1,606[a]	3,136
Mean length (in)	16.7	19.7		
Mean age (yr)	6	7		
Sex ratio	3.1:	1.0		
Totals	7,299	1,773	1,898	10,970
Sex ratio	4.1:	1.0		

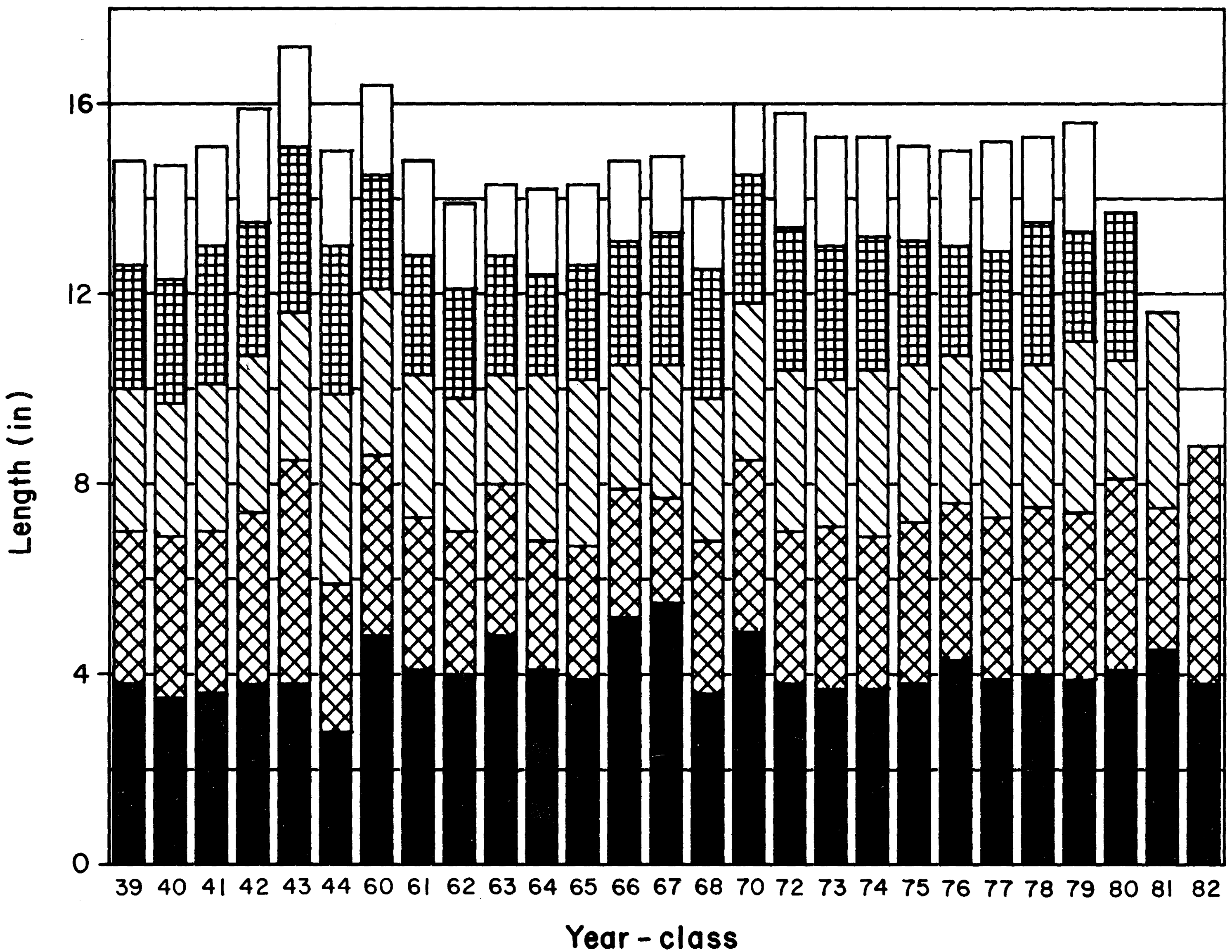
[a] Tagging done in late May and early June consisted of many spent fish for which sex was difficult to determine.

captured during the 1983 and 1984 September netting periods (Table 18). Growth varied but no trends showing faster growth to recruitment as the sport fishery expanded were apparent (Fig. 15). Growth was least for cohorts formed in the 1960's. The 1966 year-class was very abundant and grew rapidly in its first year, supporting the hypothesis that strong year-classes correlate with rapid first year growth. Relatively faster and less variable growth to age 5 occurred for cohorts formed in the 1970's. Increased growth

Table 18. Calculated mean length (in) at each annulus for male and female walleye, Lake of the Woods, Minnesota, 1968-70[a] and 1983-84.

	Number in sample	Mean calculated length at each annulus													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Males															
1983	124	5.4	8.3	10.9	13.1	14.7	16.0	16.9	17.3	9.7	20.0				
1984	142	5.6	8.5	11.3	13.3	15.0	16.3	17.2	18.0	19.7	20.0				
Grand mean															
1983-84	266	5.5	8.4	11.2	13.2	14.9	16.2	17.0	17.8	19.7	20.0				
1968-70	163	6.8	9.2	11.5	13.7	14.9	15.9	17.1	17.8	18.6	19.2				
1968-70	163	6.8	9.2	11.5	13.7	14.9	15.9	17.1	17.8	18.6	19.2				
Females															
1983	95	5.6	8.5	11.2	13.4	15.0	16.5	17.5	19.4	20.9	21.2	23.7	24.5	24.9	25.4
1984	204	5.8	8.6	11.5	13.7	15.5	17.2	18.8	21.1	23.6					
Grand mean															
1983-84	299	5.7	8.6	11.4	13.5	15.3	16.9	17.9	20.0	21.8	21.2	23.7	24.5	24.9	25.4
1968-70	175	6.9	9.2	11.7	13.9	15.5	16.9	18.0	19.7	20.6	22.5				
1968-70	175	6.9	9.2	11.7	13.9	15.5	16.9	18.0	19.7	20.6	22.5				

[a] From Schupp (1974).



... to each age for each year class. Back calculation rates for females were evident by age 4, ranging from 0.2in during the first three years to 0.9in at age 7. A Walford plot for females ages 1-14 estimated l_∞ as 29.6in and k as 0.132 while for males ages 1-10 l_∞ was estimated as 23.2in and K as 0.188.

The fecundity-body weight relationship from 40 female walleye sampled in 1983 (Table 19) was linear and resulted in an estimate of 22,834 eggs for a 1 lb female (Fig. 16). Carlander (1942) estimated 22,655 eggs per 1 lb female for 9 fish examined in 1941. Assuming that an average female spawner weighed 3 lb and contained approximately 82,000 eggs (Fig. 16), an estimated 500,000 female spawners would annually deposit an estimated 41 billion eggs in Minnesota waters of Lake of the Woods. Serns (1982a) estimated a survival rate (S) of 0.000276 (instantaneous rate, Z = 8.195) from egg to fry in the fall in Escanaba Lake, Wisconsin, while Noble (1972) found S = 0.05 (Z = 3.00) for fry in mid-summer in Oneida Lake, New York. The difference between the two instantaneous rates represents an estimated egg mortality of A = 0.99446 (Z = 5.195), and when applied to the estimated egg deposition, yields an estimate of 227 million fry present in the Minnesota waters of Lake of the Woods at the beginning of each year.

Comparisons of commercial CPUE indicate the presence of 2.3 times as many commercially legal walleye during 1980-84 as in 1968-70 and that relative abundance was not related to commercial fishing effort (Fig. 17). Walleye CPUE in commercial gill nets increased to peak levels in 1973 due to recruitment of the exceptionally large 1966 year-class (Fig. 18). Commercial gill net CPUE subsequently maintained consistently higher levels, yielding an average of 172,110 lbs (SE 13,680) per year after 1973 (Fig. 19). Average CPUE for 1972-84 (40.6 lb/1,000 ft. net) was significantly greater ($p < .0005$) than that for 1950-71 (26.8 lb/1,000 ft. net) when tested with a

Table 19. Female walleye from the Rainy River at Birchdale, Minnesota, on 21 April 1983.

Sample number	Body length (in)	Body weight (lb)	Number of eggs	Scale age	Spine age
1	16.2	1.5	33,898	5	5
2	16.6	1.6	34,005	6	5
3	16.8	1.7	57,066	6	6
4	17.5	1.8	57,976	7	6
5	17.5	1.9	71,923	6	6
6	17.6	2.2	57,035	7	7
7	18.2	2.1	51,002	7	7
8	18.2	2.3	72,158	6	6
9	18.2	2.1	57,409	7	7
10	18.2	2.0	67,484	7	7
11	18.3	2.2	73,868	6	8
12	18.3	2.3	68,772	7	7
13	19.3	2.7	68,137	7	7
14	19.4	2.6	69,956	6	6
15	19.4	2.4	79,988	6	7
16	19.5	2.7	76,183	8	7
17	19.7	2.7	79,024	7	7
18	20.0	2.8	85,401	7	7
19	20.2	2.8	94,954	8	7
20	20.3	2.8	75,977	8	7
21	20.7	3.3	86,382	7	8
22	20.8	3.3	94,449	7	9
23	21.0	3.3	118,477	7	7
24	21.1	3.5	117,288	7	7
25	21.5	3.6	124,664	-	7
26	21.8	3.7	119,931	8	7
27	21.9	3.7	83,113	9	8
28	22.3	3.8	115,855	8	8
29	22.4	4.3	130,397	9	8
30	22.9	4.4	148,907	10	10
31	24.0	5.5	166,991	10	10
32	24.1	4.9	141,416	9	9
33	24.6	5.2	153,301	10	10
34	24.7	6.0	223,772	11	13
35	25.5	6.6	223,108	10	11
36	25.7	7.1	221,562	9	11
37	26.5	7.5	255,679	11	12
38	26.6	9.1	274,519	10	15
39	27.5	8.1	274,022	13	11
40	28.6	9.3	299,956	-	16

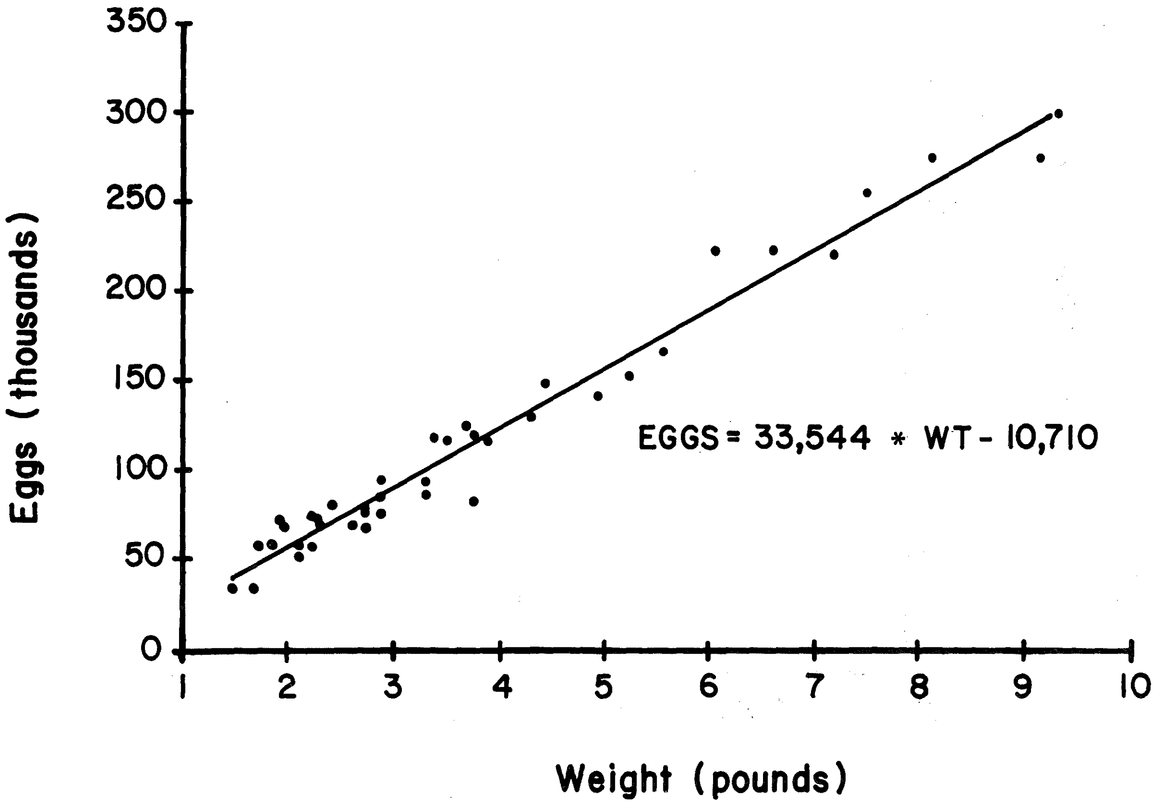


Figure 16. Relationship of number of eggs to walleye weight from the Rainy River, April 1983.

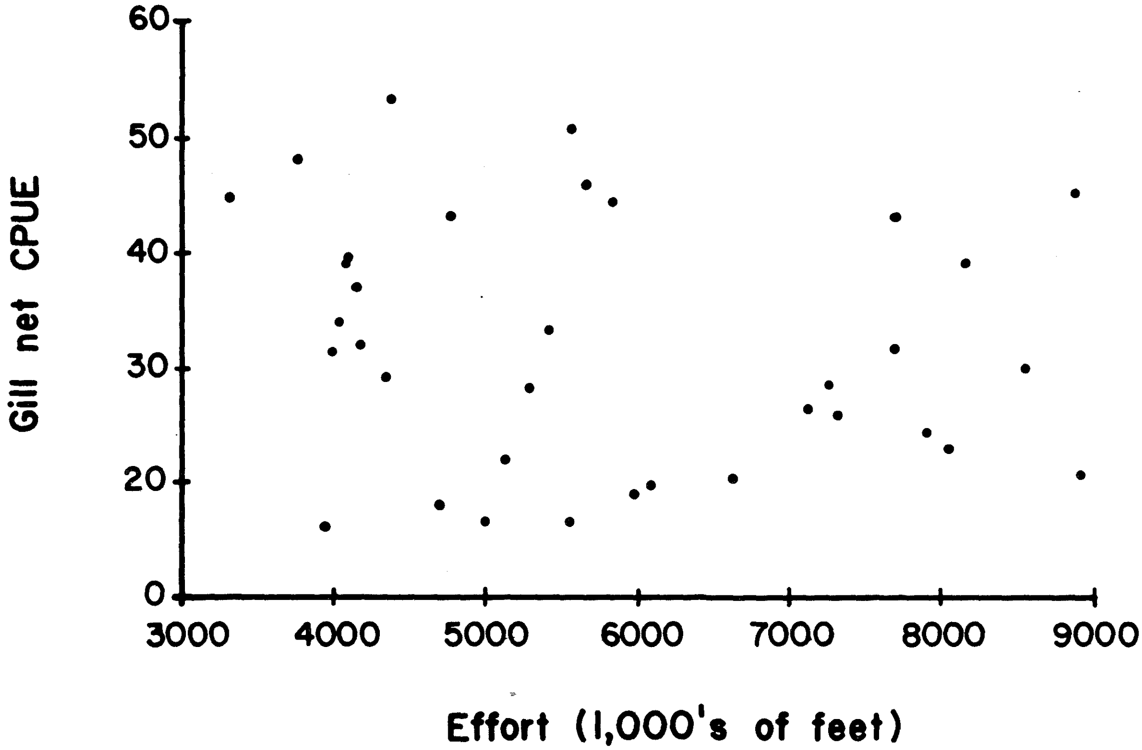


Figure 17. Relationship between commercial gill net effort and catch per unit of effort, Lake of the Woods, Minnesota.

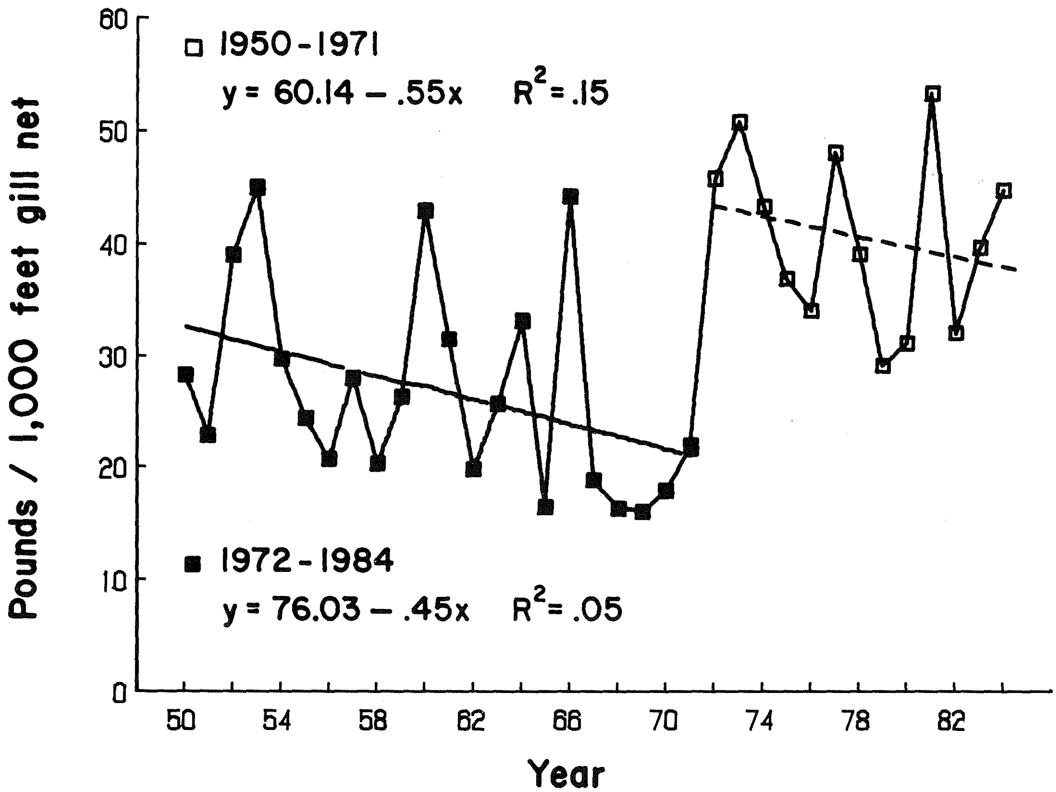


Figure 18. Relationship between commercial gill net effort and CPUE, Lake of the Woods, Minnesota.

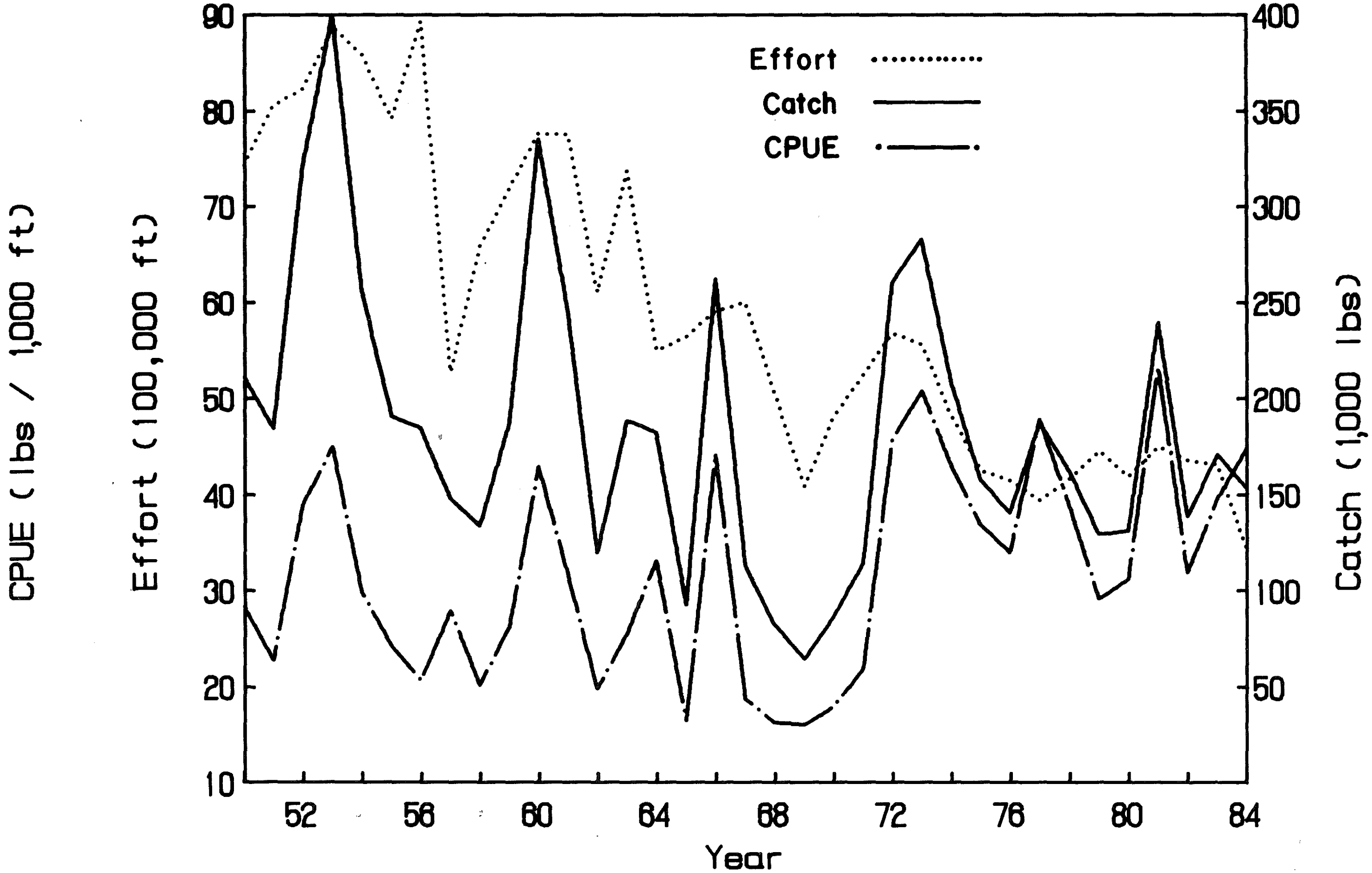


Figure 19. Trends in commercial gill net catch, effort and catch per unit of effort.

one-tailed t-test and was exceeded only three times during the earlier period. CPUE was regressed against time for both of the above periods. Both F-tests were non-significant ($F = .56$, $p > .05$ for 1950-71 and $F = 0.6$, p .25 for 1972-84) and the perceived downward trend for both periods indicated by negative slopes is not significant (i.e. neither slope differs from zero). During the later part of the 1984 season, gill net operators were moving away from walleye concentrations to avoid exceeding walleye quotas. The 1984 CPUE of 44.7 lb/1,000 ft of gill net would probably have exceeded the 1981 figure of 53.3 lb/1,000 ft had the quota not been in effect (Table 20).

Mortality Estimates

Mortality estimates during the current study were similar to those from both the 1940's (Carlander 1942) and the 1960's (Schupp 1974). The instantaneous rate of total mortality (Z) for walleye age 4 through 9 was 1.04 (95% confidence interval from 0.77 to 1.31, $R^2 = .966$) from 1980-84, equivalent to an annual mortality rate of 65%. In comparison, Schupp (1974) estimated a total annual mortality rate of 55% ($Z = .80$) from index net catches for ages 4 through 10 for the period of 1968-70. Estimates of total mortality derived separately for the July and September sampling periods did not substantially differ. The estimate of Z for July was 1.07 (95% confidence interval from 0.79 to 1.38) and for September was 1.02 (95% confidence interval from 0.77 to 1.28). The estimate of Z from the length converted catch-curve method of Pauly (1983) was 0.604, equivalent to an annual mortality rate of 45%.

Total mortality rate was also estimated from commercial and sport tag returns. The estimate of Z thus derived was 1.25, equivalent to a 71% annual mortality rate. For two complete sport fishing seasons, 1982-83 and 1983-84, the logarithmic regression yielded an instantaneous rate of 1.49 or an annual

Table 20. Commercial harvest (lb) of walleye from Minnesota waters of Lake of the Woods, 1945-1984.

Year of harvest	Harvest (lb)	Gill net CPUE (Per 1,000 ft)
1945	367,538	[a]
1945	345,714	
1947	299,855	
1948	303,090	
1949	419,154	32.3
1950	353,671	28.3
1951	257,681	22.8
1952	366,487	39.0
1953	480,835	45.0
1954	326,307	29.8
1955	233,639	24.2
1956	245,472	20.6
1957	204,531	28.0
1958	170,278	20.2
1959	220,345	26.2
1960	429,802	43.0
1961	318,266	31.5
1962	155,722	19.7
1963	224,932	25.6
1964	217,030	33.1
1965	140,888	16.4
1966	305,218	44.3
1967	138,180	18.8
1968	105,422	16.4
1969	79,086	16.0
1970	100,785	17.9
1971	129,435	21.9
1972	286,922	45.8
1973	312,115	50.7
1974	234,194	55.9
1975	189,361	36.9
1976	167,567	34.0
1977	225,878	48.0
1978	185,412	39.0
1979	145,663	29.1
1980	139,155	31.2
1981	250,922	53.3
1982	157,074	32.0
1983	184,975	39.6
1984	160,261	44.7
1985	14,483	49.4
1986	-o-	-o-

[a] Data unavailable.

mortality rate of 78%. Tag returns used for this estimate included those reported voluntarily by anglers and those observed in the creel. Total mortality estimated from tag returns may be unreliable due to only two and three years data from the sport and commercial fisheries, respectively. Total mortality estimated from assessment netting may also be affected by age-specific seasonal movements of walleye. A Chi-square test to compare distributions of age 4-9 walleye between July and September assessment net catches showed that age distribution differs between these two months ($p < 0.025$). However, age 5 walleye contributed a large amount to the total Chi-square and there was no strong evidence to suggest differential seasonal vulnerability to the index nets of walleye age 6 and older.

Instantaneous natural mortality (M) was estimated by the method of Pauly (1979). Separate growth parameters for females age 1-14 and males age 1-10 were estimated from the 1983-1984 assessment net catches. The estimate of M for females was 0.206 (95% confidence interval from 0.128 to 0.333) and for males is 0.278 (95% confidence interval from 0.172 to 0.449).

Population Estimates

The number of tagged fish which were not vulnerable to commercial gill nets (2.0in bar mesh) due to gear selectivity was estimated by comparing length-frequencies of all tagged fish in each stratum with those recaptured by the four selected commercial fishermen (Table 21). The numbers marked and vulnerable to commercial gill nets in each stratum were:

Stratum	Number marked	Number vulnerable for recapture by commercial gill nets
South	4,338	2,534
West	3,496	1,788
North	3,136	2,322

Table 21. Percent of tagged fish in each commercial licensee's catch, Lake of the Woods, Minnesota, 1982.

	Commercial fishery number (no of licenses)							
Month	1(4)	2(3)	3(1)	4(1)	5(1)	6(1)	7(1)	8(3)
June	0.57	0.81	0.57	0.45	1.01	1.00	0.61	4.62
July	0.28	0.32	1.01	0.83	0.69	1.13	0.16	1.49
August	0.49	0.81	0.37	0.46	0.80	0.67	0.27	NT[a]
Sept.	0.98	0.37	1.00	1.22	0.84	1.37	0.10	1.28
Oct.	0.69	0.28	1.71	1.14	1.31	1.40	0.06	1.03
Total	0.64	0.54	0.94	0.79	0.95	1.13	0.16	1.54
Rank	5	6	3	4	2	1	7	EX[b]

[a] No tags reported.
[b] Excluded from ranking due to differences in gear.

It is important to note that recaptures occurred in the north stratum only in the month of June (Table 22). Estimates for this stratum do not reflect true dispersal rates of walleye tagged at the Flag Island site. Using the notation of Chapman and Junge (1956), s_{ij} is the number of walleye tagged in stratum i and recaptured in a sample from stratum j. This translated to the following recapture matrix:

		$s_{.j}$		
		SOUTH	WEST	NORTH
$s_{i.}$	SOUTH	69	45	6
	WEST	29	54	5
	NORTH	5	11	17
		103	110	28

Table 22. Monthly tag returns from each stratum by commercial fishery numbers 3-6, Lake of the Woods, Minnesota, 1982.

Month	Strata sampled for recaptures: South	West	North	Total
June	18	0	28	46
July	30	23	0	53
August	4	19	0	23
September	26	32	0	58
October	25	37	0	62
Total	103	111	28	242

Therefore, only 28 recaptures were reported from the north stratum. The following number of walleye were examined for marks in each stratum: SOUTH 11,940; WEST 10,544; NORTH 2,748.

Assuming that all tagged fish caught by the four selected gill net fishermen were reported, the following population estimates (95% confidence intervals) for mature walleye vulnerable to the commercial gill nets were obtained with a stratified and with the Chapman modification of the Peterson estimate (Ricker 1975):

STRATIFIED: 681,709 (540,686 to 822,731)

STANDARD: 691,052 (609,589 to 783,357)

Again it should be emphasized that these are estimates of the number .

Using the notation of Chapman and Junge (1956), N_{ij} is the number of walleye that are in stratum i at the time of tagging and in stratum j at time of sampling. The following matrix was computed:

	SOUTH	WEST	NORTH	$N_{i.}$
SOUTH	177,862	79,173	107,015	364,050
WEST	27,828	34,599	33,198	95,626
NORTH	8,452	12,547	200,944	222,033
$N_{.j}$	214,232	126,320	341,157	681,709

Therefore at the time of tagging, the south stratum (Birchdale and Four Mile Bay tag sites) had the largest aggregation of fish with 364,049 ($N_{1.}$); the west stratum (Elm Point tag site) had the least with 95,625 ($N_{2.}$); and the north stratum (Flag Island tag site) was intermediate with 222,033 ($N_{3.}$). Comparing the $N_{i.}$'s with the $N_{.j}$'s gave an indication of spawning aggregation dispersal. The south stratum had a net loss of 149,817 walleye, with a value of 214,232 ($N_{.1}$) at the end of the period. These fish dispersed mostly to the north stratum (N_{13} = 107,015). The west stratum showed a net gain of 30,694 walleye. Most of these fish migrated from the south stratum (N_{12} = 79,173). Finally, the north stratum also showed a net gain of walleye with a value of 341,156 ($N_{.3}$) at the end of the sampling period. However, as indicated previously, estimates of dispersal from the north stratum are minimal (N_{31} = 8,452 and N_{32} = 12,547), since uneven distribution of commercial fishing effort resulted in no recaptured walleye after the month of June in this stratum. Estimates of the number of walleye emigrating from the west and south strata to the north are minimal for the same reason.

Stratified and standard Peterson estimates were also calculated for different tag reporting rates by the four commercial fishermen (Table 23). It is doubtful that even the most efficient cooperators were able to account for all of their recaptured tags. A reporting rate of 90% may be a reasonable choice for use of population estimates in further analyses. Tag-shedding and non-reporting of tags are confounding events and estimates of reporting rate will account for tag-shedding. Finally, standard Peterson estimates were also calculated individually for all strata (Table 24).

Estimates of Tag Reporting Rates and Exploitation

The U.S. commercial harvest of walleye in 1982 was approximately 157,074 pounds and the average size of each walleye was 2.2 lb. It is therefore

Table 23. Stratified and standard Peterson esimates at four reporting rates for commercial fishery numbers 3-6 (95% confidence interval), Lake of the Woods, Minnesota, 1982.

Reporting rate	Stratified estimate	Peterson estimate
100%	681,709 (540,686 to 822,731)	691,052 (609,589 to 783,357)
90%	604,502 (486,373 to 722,631)	619,652 (550,241 to 697,788)
80%	542,314 (440,374 to 644,254)	552,387 (493,763 to 617,950)
70%	474,966 (391,935 to 557,998)	483,935 (435,683 to 537,518)

Table 24. Peterson estimates for each stratum at four reporting rates for commercial fishery numbers 3-6 (95% confidence intervals), Lake of the Woods, Minnesota, 1982.

Reporting rate	Stratum		
	South	West	North
100%	248,118 (207,946 to 295,982)	211,966 (172,424 to 260,461)	188,630 (135,590 to 270,608)
90%	222,577 (188,276 to 263,078)	190,556 (156,658 to 231,705)	168,774 (123,335 to 237,534)
80%	197,846 (168,954 to 231,645)	169,955 (141,237 to 204,454)	152,700 (113,311 to 210,968)
70%	172,974 (149,227 to 200,478)	149,722 (125,833 to 178,108)	133,613 (100,999 to 180,670)

estimated that commercial fishermen harvested 72,052 individual walleye. With the estimate of 604,502 walleye vulnerable to the commercial gear derived in this study, the estimated rate of exploitation for this population was

$$u_v = 72{,}052/604{,}502 = 0.1192$$

From a total of 10,970 tagged walleye, the number vulnerable to commercial gill nets was estimated by comparison of length frequency distributions between commercial tag returns and all tagged fish (Ricker 1975). This yielded an estimate of 6,644 tagged walleye vulnerable to the commercial gear. The estimated number of vulnerable, tagged walleye caught in U.S. commercial gear was

$$T_u = 0.1192*6644 = 792$$

and the tag reporting rate of U.S. commercial fishermen was

$$R_c = 536/792 = 0.676.$$

The total number of voluntary tag returns by U.S. (536) and Ontario (83) commercial fishermen for 1982 was 619. Assuming a similar reporting rate for these two groups, the estimated number of tagged walleye captured in all commercial gear was

$$T_c = 619/.676 = 916.$$

Finally, the estimated rate of commercial exploitation for all tagged fish was

$$u_c = 916/10{,}959 = 0.084$$

which corresponds to an instantaneous rate (F_c) of 0.134.

By subtraction, the instantaneous sport fishing mortality was

$$F_s = 1.04(Z) - 0.242(M) - 0.134(Fc) = 0.664$$

which converts to an exploitation rate of .415 (u_s). The estimated number of tagged fish harvested by anglers was

$$T_s = .415*10{,}959 = 4{,}548$$

and the tag reporting rate for anglers was

$$R_s = 1488/4{,}548 = 0.327.$$

Estimates of sport reporting rates are sensitive to other estimates of mortality. The primary source of error in the derivation above was in the estimate of Z used. Using the earlier estimate of Z equal to 0.80 provided by Schupp (1974), F_c is 0.122 and F_s is 0.436. This results in a U_s of 0.30 and a sport reporting rate of 0.453.

Sex-specific exploitation rates for mature walleye (males >11.0in and females >13.0in) were calculated for both the sport and commercial fisheries from voluntary returns (Table 25). Commercial tag returns included only those returned by U.S. fishermen. Anglers exploited males at a greater rate than females at all tag sites except Elm-Buffalo Point. The exploitation rate of tagged females by commercial gear was greater than that of males at all tag sites except Flag Island. The ratio of male to female tagged walleye in the sport fishery was approximately 5.4 to 1 and in the commercial fishery was 2.5 to 1. The sport and commercial tagged sex ratios differed significantly (X^2 = 37.7) and both sport and commercial tagged sex ratios differed from the ratio of 4.1 to 1 for all tagged fish (X^2 = 10.4 and 24.1, respectively). In comparison, the sex ratio of all walleye in the commercial fishery from 1980-84 was 1:5.

Exploitation rates were also calculated by size at time of tagging for the sport and commercial fisheries based on voluntary tag returns (Table 26). The rate of commercial exploitation calculated here includes tags reported by both U.S. and Ontario fishermen. A moving average of three 1.0in group intervals was used to smooth variability due to sampling error. Standard

Table 25. Percent voluntary tag returns for each tag site from all volunteered angler and U.S. commercial tag returns 15 May through 31 October 1982.

	Birchdale			Elm-Buffalo		
	Female	Male	Unk.	Female	Male	Unk.
Number tagged	415	2581	32	617	2642	237
Sport returns	46	483	3	57	227	23
Exploitation rate	.111	.189	.103	.093	.086	.097
Commercial returns	33	126	0	78	154	16
Exploitation rate	.080	.049	---	.127	.058	.068

	Four Mile Bay			Little Traverse		
	Female	Male	Unk.	Female	Male	Unk.
Number tagged	372	945	23	369	1161	1606
Sport returns	53	174	7	30	123	135
Exploitation rate	.142	.184	.320	.081	.106	.084
Commercial returns	20	32	0	7	28	43
Exploitation rate	.054	.034	---	.019	.024	.027

Table 26. Size-specific exploitation rates for all voluntary commercial tag returns in 1982 and all voluntary sport tag returns from 15 May 1982 through 14 April 1983.

Total Length	Commercial		Sport	
(in)	Female	Male	Female	Male
11	0[a]	.0036[a]	0[a]	.100
12	0[a]	.0101	0[a]	.1315
13	.0513[a]	.0119	.1282	.1435
14	.0547	.0232	.1094	.158
15	.0627	.047	.1203	.166
16	.0844	.068	.1176	.1644
17	.0994	.0872	.1187	.155
18	.1082	.1048	.1277	.1356
19	.1105	.1140	.1361	.1009
20	.088	.1183	.1493	.0699
21	.0962	.1194	.1154	.0299[a]
22	.073	.25[b]	.073	.05[a]
23	.0863	.20[a]	.036	0[a]
24	.0602	.20[a]	.0451	0[a]
25	.0583	0[a]	.0667	0[a]
26	.0294[a]	0	.0588	0[a]
27	.0133[a]	NT[c]	.0533	NT
28	.0167[a]	NT	.0167[a]	NT
29	.0263[a]	NT	.0263[a]	NT
30	.0526[a]	NT	0[a]	NT
31	0[a]		NT	
0[a]	NT			

[a] Coefficient of variation greater than 0.5.
[b] Highly significant outlier.
[c] No fish tagged in this size interval.

deviations were calculated for each 1.0in size interval based on the binomial distribution (Snedecor and Cochran 1967). Due to small sample sizes and the use of the moving average technique, exploitation may have been overestimated at extremes of the size range, thus an a priori test was applied to delete spurious data points before fitting polynomial curves. If the coefficient of variation, defined as the ratio of the standard deviation over the estimate of exploitation was greater than 50%, the estimate was excluded from the regression. In the case of male commercial exploitation rates, the estimate at 22in was deleted based on a highly significant outlier test ($p < 0.01$) and a large estimate of Cook's distance (Weisberg 1980). Polynomial regression was used to fit curves describing the relationship between size and exploitation rates for each fishery and each sex (Figs. 20 and 21). The F_p statistic at the 5% level (Weisberg 1980) was used to test the addition of polynomial degrees. The following curves were developed for each fishery:

<u>Commercial fishery</u>:

Female: $Y = -.4912 + .6127E\text{-}1X - .1585E\text{-}2X^2$ $R^2 = .7908$

Male: $Y = 5.2191 - 1.2561X + .1096X^2 - .4092E\text{-}2X^3 + .5583E\text{-}4X^4$ $R^2 = .9996$

<u>Sport fishery</u>:

Female: $Y = 6.1625 - 1.3535X + .1111X^2 - .3947E\text{-}2X^3 + .5114E\text{-}4X^4$ $R^2 = .8154$

Male: $Y = -.7448 + .1207X - .3998E\text{-}2X^2$ $R^2 = .9901$

Polynomial approximations may deviate considerably from the true relationship outside the range of fitting and should therefore be used only for interpolation. Maximum exploitation of tagged female walleye occurred at a size of approximately 19 to 20in in the commercial fishery and 20 to 21in in the open-water sport fishery. Maximum exploitation of male walleye occurred at approximately 21in in the commercial fishery and 15 to 16in in the open-water sport fishery.

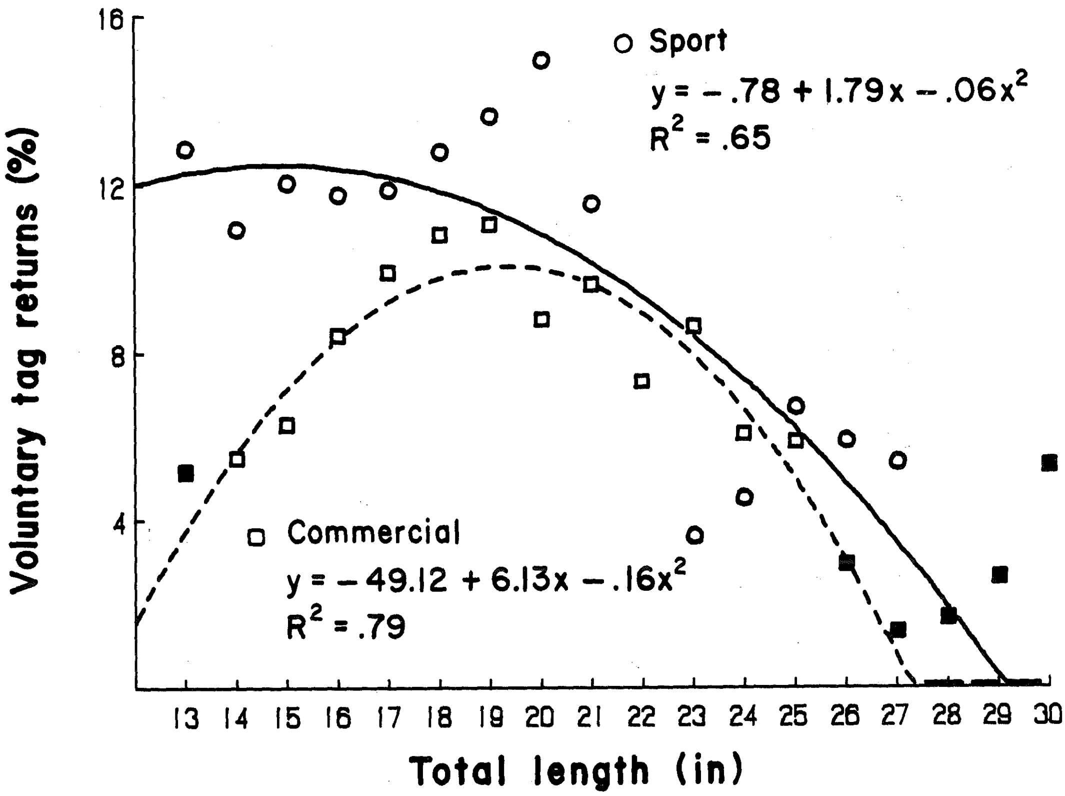


Figure 20. Female size-specific exploitation rates for sport and commercial fishing, Lake of the Woods, 1982. Solid symbols represent estimates with a large coefficient of variation omitted from the regression.

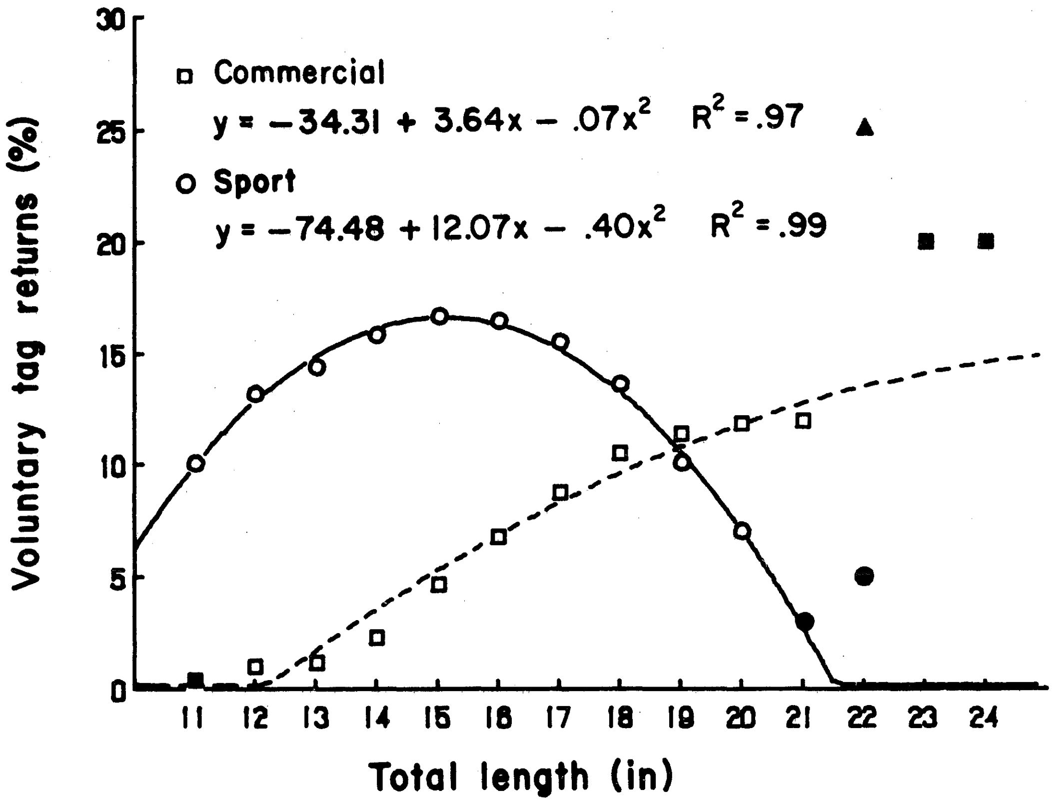


Figure 21. Male size-specific exploitation rates for sport and commercial fishing, Lake of the Woods, 1982-84. Solid symbols represent estimates with a large coefficient of variation omitted from the regression. The solid triangular symbol represents the estimate omitted as an outlier.

LOGIT ANALYSIS

The initial logit analysis was done using only voluntary tag returns and the most parsimonious model for the Gear by Season by Sex model was the "no second order interaction" model (G^2 = 3.301, 4 d.f., $p > .5$). As determined by voluntary tag data, the total harvest of female walleye was dominated by the sport fishery from spring through early summer and the commercial fishery from mid-summer through fall (Fig. 22). This shift from the sport to commercial harvest did not occur for male walleye until late summer. Voluntary tag returns for the full fishing year from 15 May 1982 through 14 April 1983 were used for the Gear by Size by Sex logit model. The most parsimonious model was one of conditional independence: gear type and sex are independent, conditional on fish size (G^2 = 17.24, 12 d.f., $p > .1$). For size intervals which had both sport and commercial tag returns (14-24in), the log-mortality ratios were the same for both sexes since sex and gear are conditionally independent (Fig. 23). Under this model, the commercial fishery accounted for a majority of the total harvest only for walleye between 22 and 25in.

Correcting for reporting rates inflates the G^2 statistics so that only the fully saturated model which includes the second order interaction will explain the distribution of tag returns under both of the logit models tested above. Under the fully saturated model, expected cell counts equal observed counts. In the Gear by Size by Sex logit model, correction with a 30% sport reporting rate (a minimal estimate) and 68% commercial reporting rate will still result in more of the total harvest of walleye between 22 and 25in appearing in the commercial fishery.

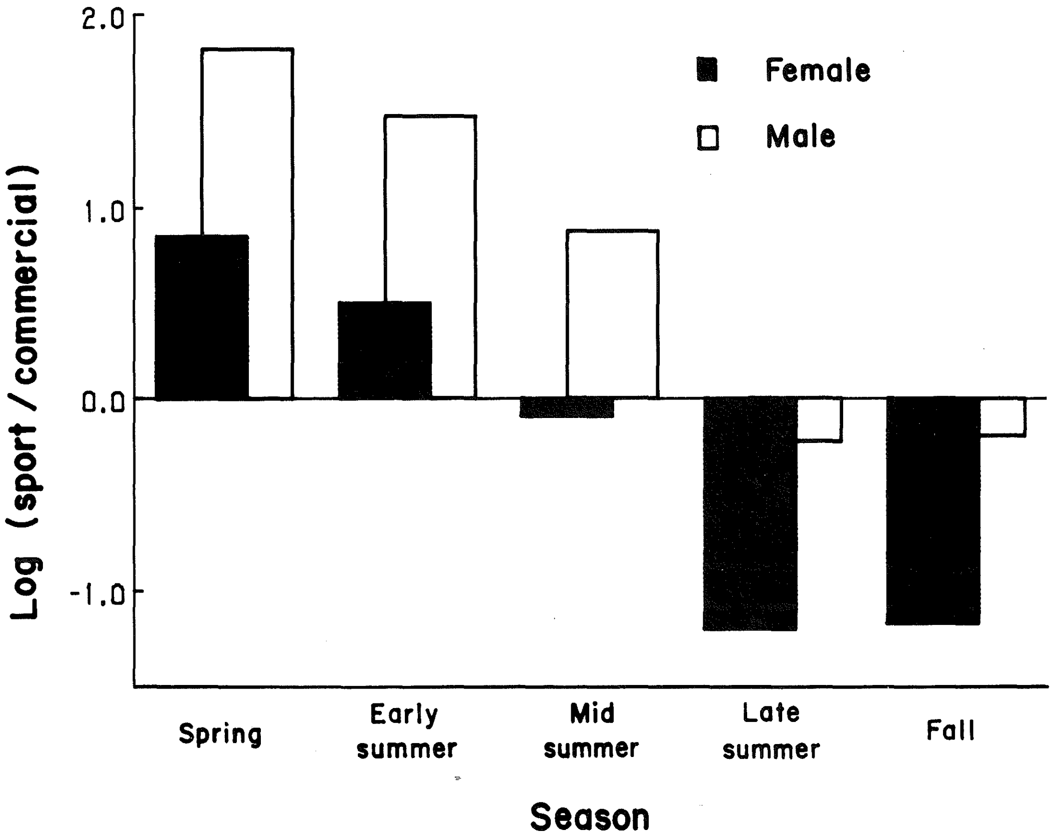


Figure 22. Log mortality ratios for the log-linear model with no second order interaction for gear by season by sex for Lake of the Woods, Minnesota, walleye, 1982-84.

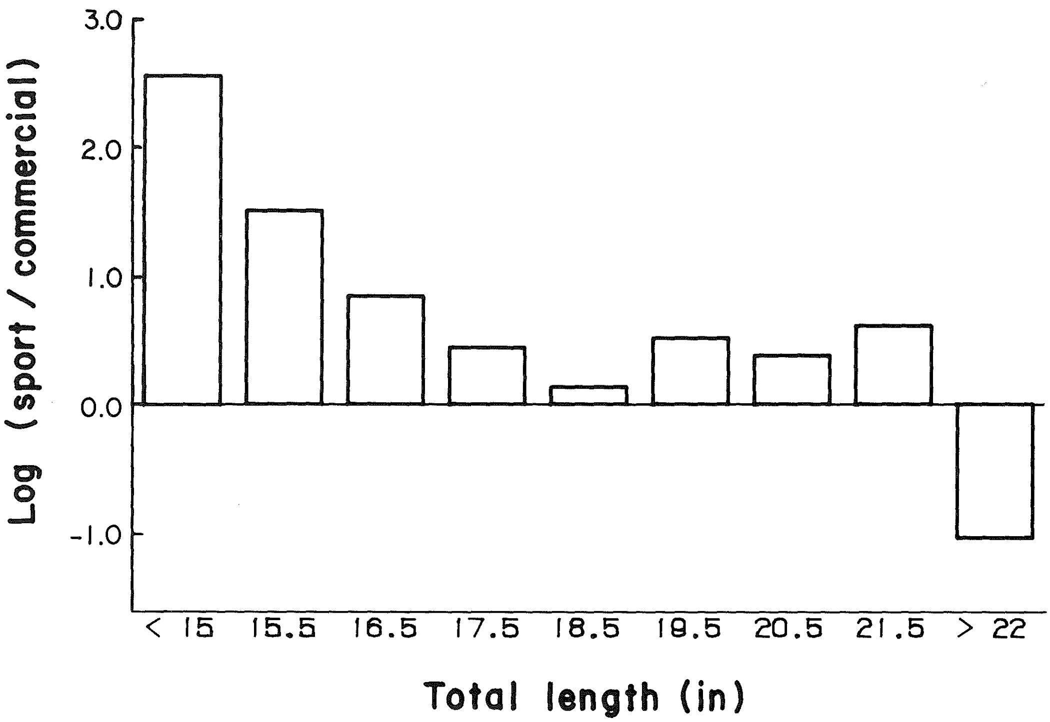


Figure 23. Log mortality ratios for the log-linear model gear by size by sex with sex being independent of gear type conditional on walleye size, Lake of the Woods, Minnesota, 1982-84.

Simulation Model

The simulation model assumed the same annual mortality rates for pre-recruits acting on constant fry production. A good fit to the empirical data resulted for the period from 1973 to 1984 (Fig. 24a) but a correspondingly good fit for years prior to 1973 could not be achieved without reducing fry production (Fig. 24b). The simulated commercial gill net catches oscillated with the actual catches because fishing effort in the model explained much of the variability in actual catches.

The differences between the actual and simulated values probably represent a failure to include in the model a mechanism to generate variability in year-class strength. Except for an increase in the number of fry in 1966, the model does not vary recruitment (year-class strength) in the simulated population. Variable recruitment occurs in most walleye populations and size-selective gear, such as 4.0in stretch mesh commercial gill nets, can produce good measures of recruitment. CPUE for gill nets fluctuated more than catch and was almost certainly a more sensitive indicator of variable recruitment (Figs. 25a and 25b). The simulated CPUE does not fluctuate because recruitment is fixed in the model and effort is estimated from rectilinear functions.

Variable recruitment can be simulated but the generating function depends on measures of the causes of such variability. Constant rapid warming has been related to increased relative abundance (Colby et al. 1979). recruitment appears to have increased and stabilized during the last 15 years and it was hypothesized that this may have been related to a warming trend in average spring temperatures (Fig. 26). The temperature recruitment function did not perform any better than the constant recruitment function (Figs. 27 and 28), nor did the other functions available in the model. Model results

Figure 24. Comparison of simulated numbers of walleye gilled (dashed line) to actual commercial gill net landings on Lake of the Woods, Minnesota.

Figure 24a. Simulated year-class strength was constant at 200 million fry each year from 1949-1984.

Figure 24b. Simulated year-class strength was constant at 125 million fry each year from 1949-1965 and 200 million fry each year from 1966-1984.

Figure 24a

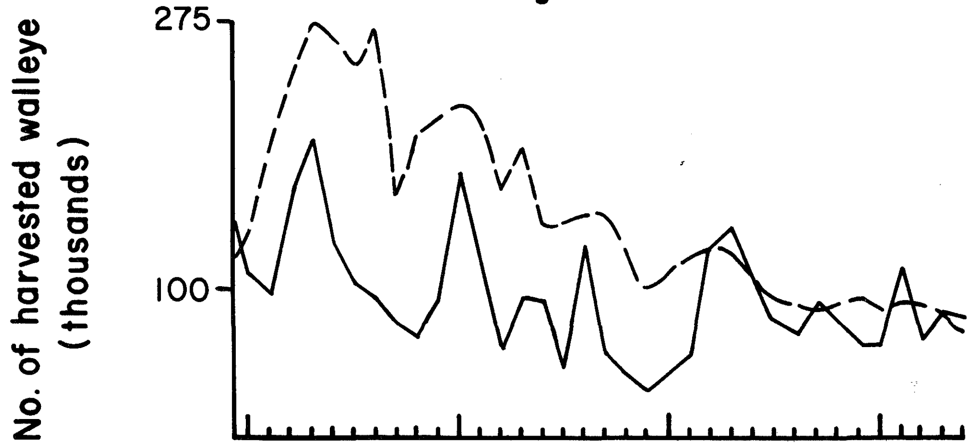


Figure 24b

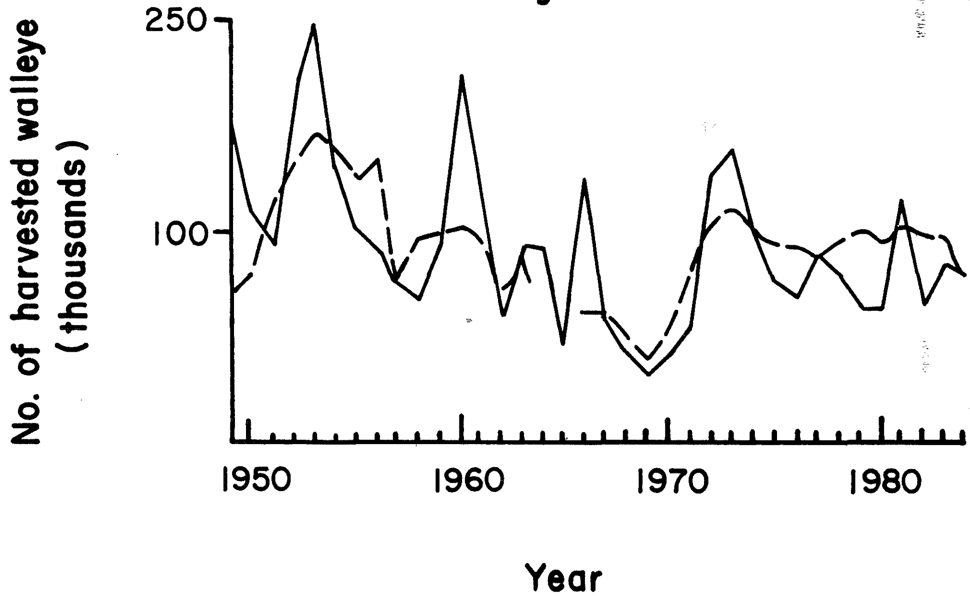


Figure 25. Comparison of simulated walleye catch per unit of effort (CPUE) (dashed line) to actual CPUE from commercial gill nets (solid line) on Lake of the Woods, Minnesota.

Figure 25a. Simulated year-class strength was constant at 200 million fry each year from 1949-1984.

Figure 25b. Simulated year-class strength was constant at 125 million fry each year from 1949-1965 and 200 million fry each year from 1966-1984.

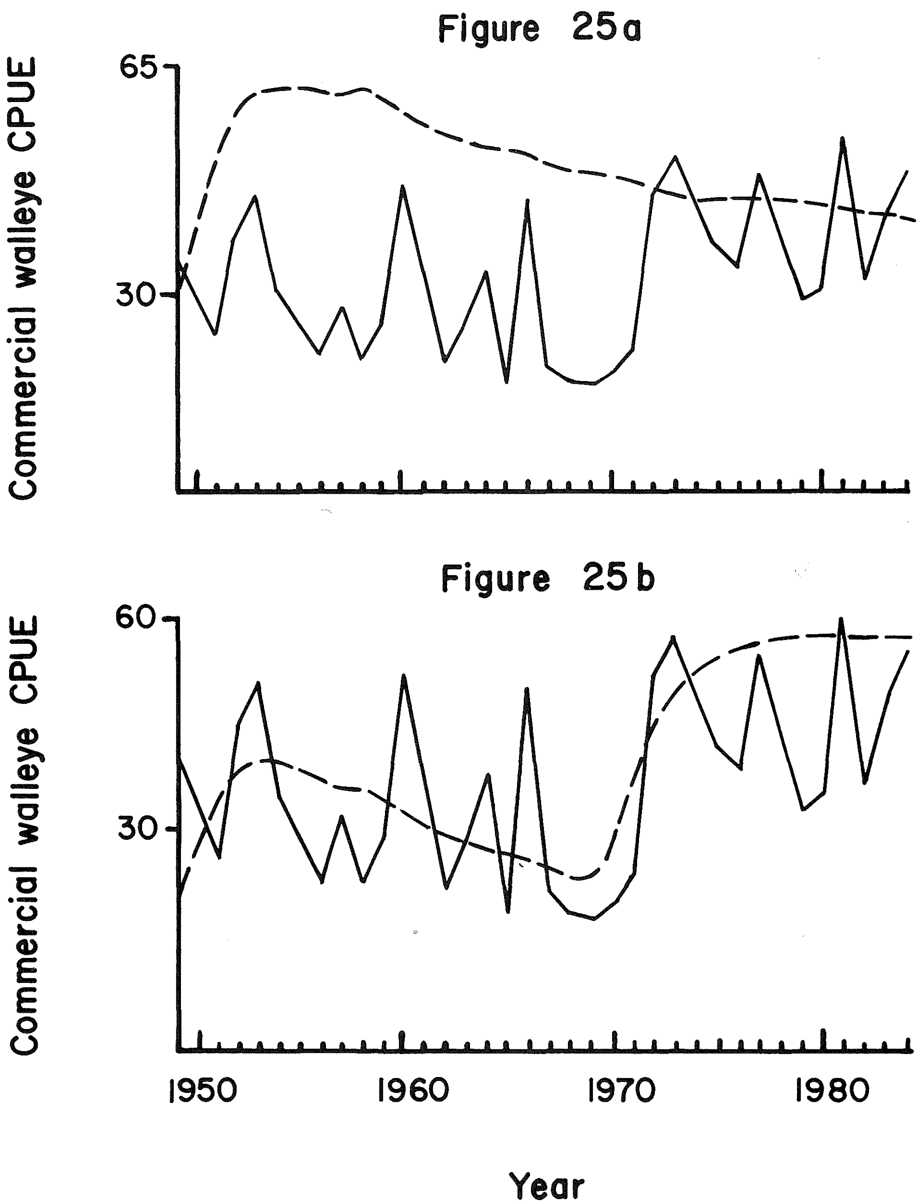


Figure 25a
65
30
Commercial walleye CPUE
Figure 25b
60
30
Commercial walleye CPUE
1950
1960
1970
1980
Year

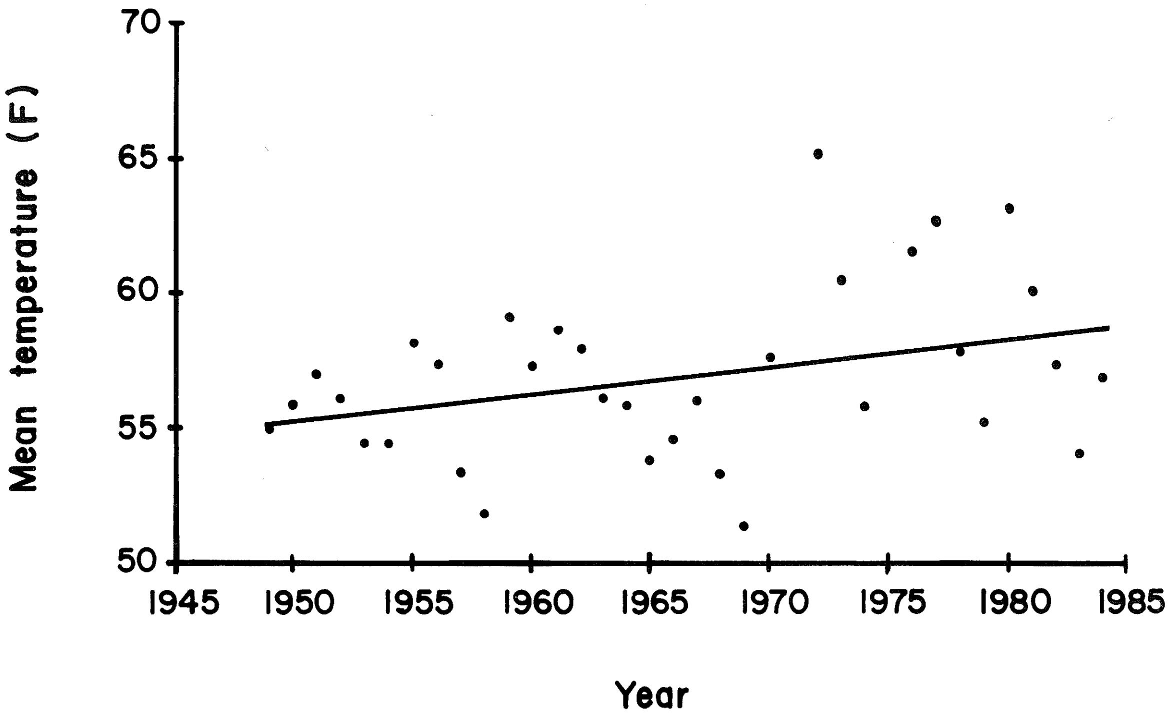


Figure 26. Trends in mean daily air temperature 15 May-15 June, Lake of the Woods, Minnesota. The hollow points were predicted from a linear regression.

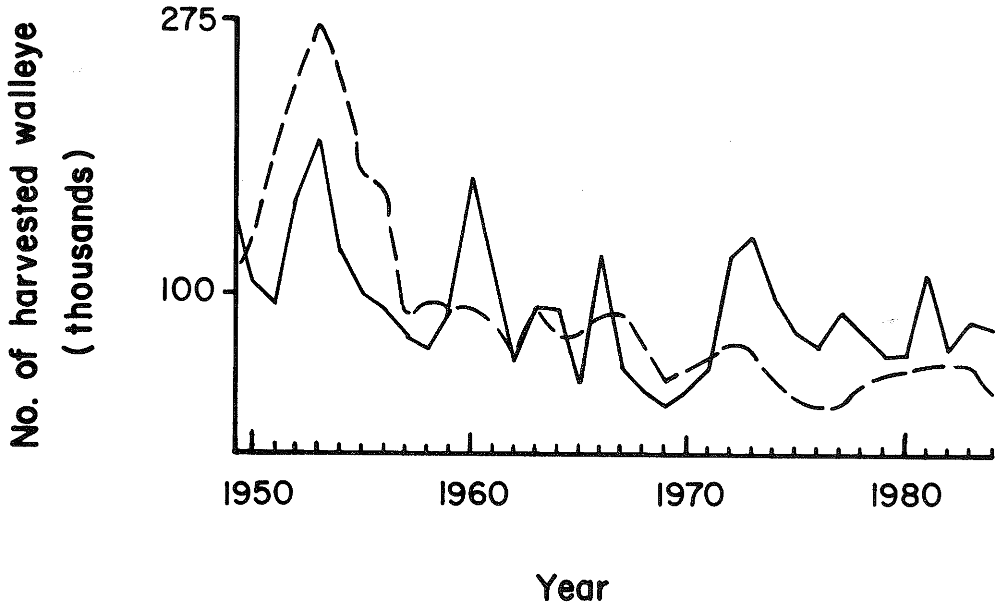


Figure 27. Comparison of simulated numbers of walleye gilled during the simulation model temperature recruitment scenario (dotted line) to actual commercial gill net landings (solid line) on Lake of the Woods, Minnesota.

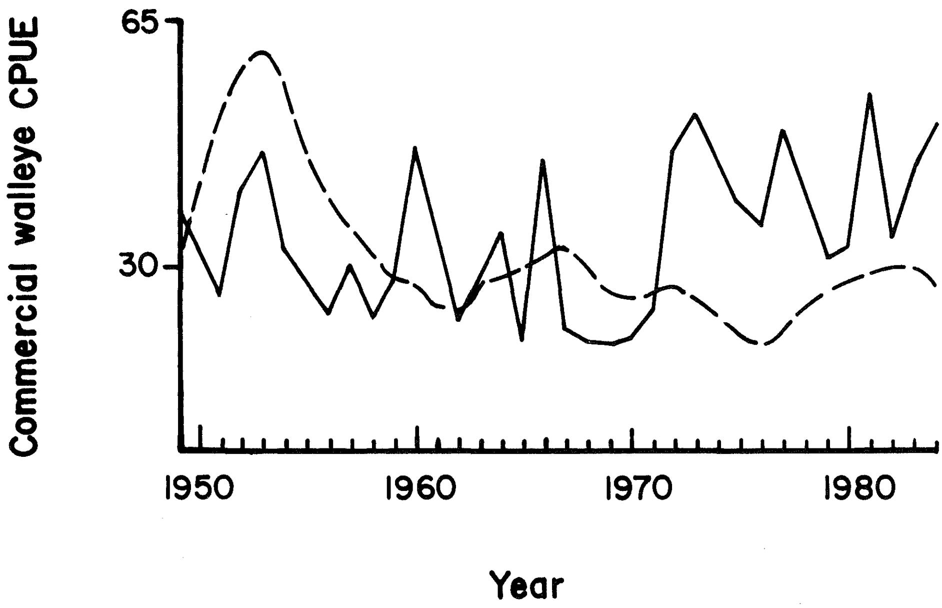


Figure 28. Comparison of simulated walleye during the temperature recruitment scenario (dotted line) to actual CPUE from commercial gill nets on Lake of the Woods, Minnesota.

indicated that some basic mechanism important to year-class formation has not been incorporated.

Simulated angler catches in the creel, creel rates and mean sizes in the catch and creel were reasonable for the period from 1949 to 1970 when the number of fry was constant (Figs. 29a and 29b). So as to simulate reduced angler efficiency with increasing effort, sport fishing mortality rates were held constant after 1970 (line 2120 in the program; Users Guide) so that creel rates would slowly decline (because of increasing fishing effort) to match creel rates from the 1982-84 surveys (Fig. 29b). When the number of fry were reduced to adjust gill net catch trends, catch rates in previous years were lower than the present period. This was counter-intuitive to many long associated with Lake of the Woods and the early trend was made more reasonable when catchability for the sport fishery was increased by 75% for the early years, although a downward spike appears in 1970 when catchability is reduced to the 1982 estimate (Fig. 30).

The historical effect of commercial and sport fisheries combined (Figs. 31 and 32) was examined. Number of walleye age 5 and older in the population declined steadily from 670,500 in 1952 to a low of 390,200 in 1969, then increased rapidly until a sustained level of 946,000 was reached in 1977. This simulated trend supports the suggestion of Schupp and Macins (1977) that the combined fisheries were having an adverse effect during the 1960s. The large year-class in 1966 and subsequent strong year-classes improved recruitment to the fisheries starting in 1972 while commercial gill net effort was concurrently declining. This decline and the decline in catchability to anglers allowed the simulated adult population to climb to the current level which is close to the 1982 tagging population estimate. These simulated results are supported by the two-fold increase in frequency

Figure 29. Simulation of the historical angling fishery, Lake of the Woods, Minnesota. Simulated year-class strength was constant at 200 million fry each year from 1949-1984. Age-specific catchability was constant.

Figure 29a. Trends are identified and scaled as follows:
9 = number creeled/425,000 (maximum = 411,000);
13 = mh/1,000,000 (maximum = 831,200);
15 = number creeled per mh/1.0 (maximum = 0.67);
17 - mean length in catch/16in (maximum = 13.8in);
18 = mean length in creel/16in (maximum = 15.1in).

Figure 29b. Comparison of simulated number creeled per mh (line 15) to "actual" trends (16), Lake of the Woods, Minnesota. "Actual" trends for 1949-1984 were scaled from CPUE from commercial gill nets during 1951-1976 (16, 16a). "Actual" trend 16b after 1974 was from a linear inverse relation between number creeled per mh and number of mh (data from the creel surveys of 1968-1970 and 1982-1984. Trend marked 14 is number caught per mh of which some are released.

Figure 29a

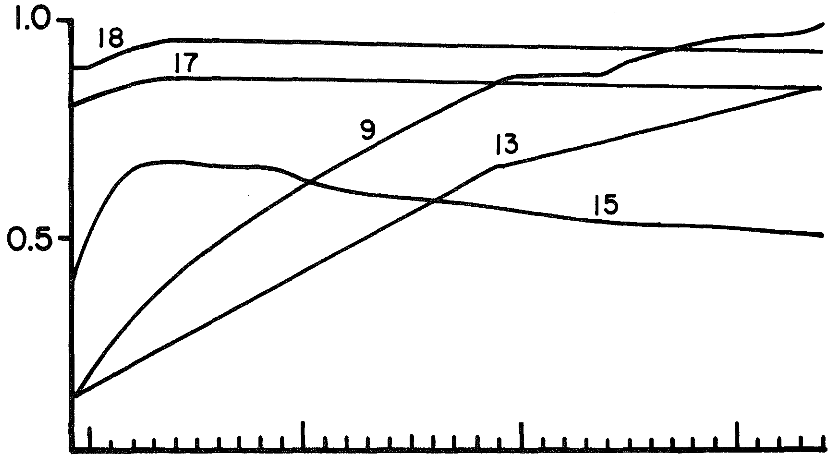
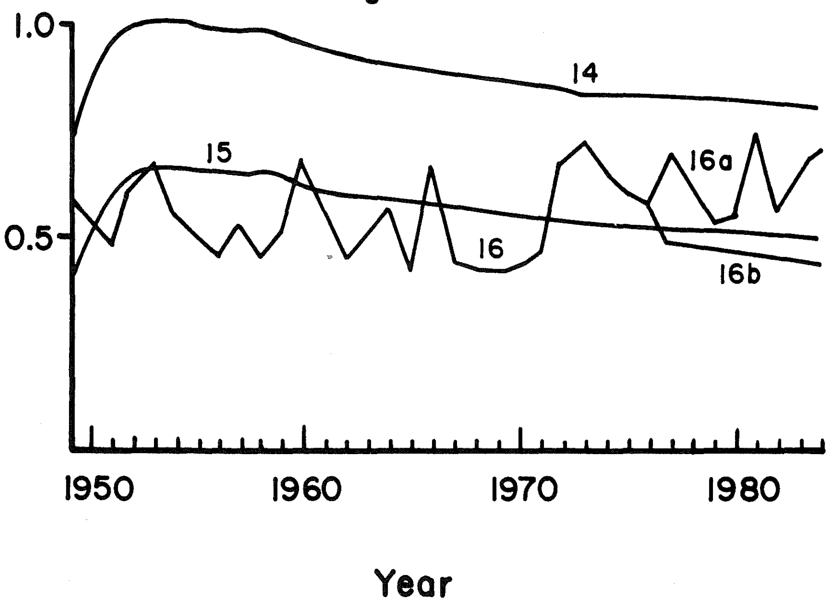


Figure 29b



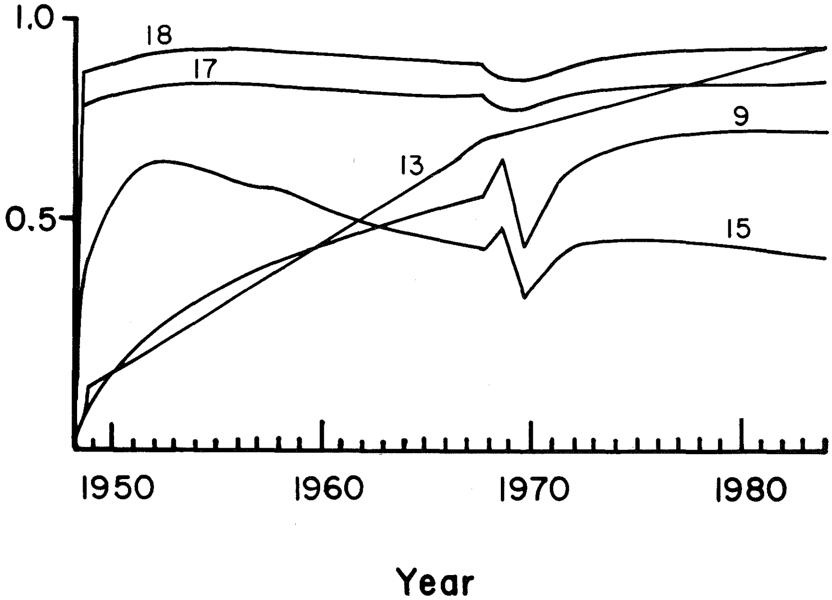


Figure 30. Simulation of the historical angling fishery, Lake of the Woods, Minnesota. Simulated recruitment was constant with 125 million fry each year during 1949-1965 and 200 million fry each year during 1966-1984. Age-specific catchability was increased by 75% for the period 1949-1970. Trends are identified and scaled as follows:
9 = number creeled/500,000 (maximum = 364,670);
13 = mn/900,000 (maximum = 831,200);
15 = number creeled per mn/1 (maximum = 0.66);
17 = mean length in catch/16in (maximum = 13.5in);
18 = mean length in creel/16in (maximum = 14.8in).

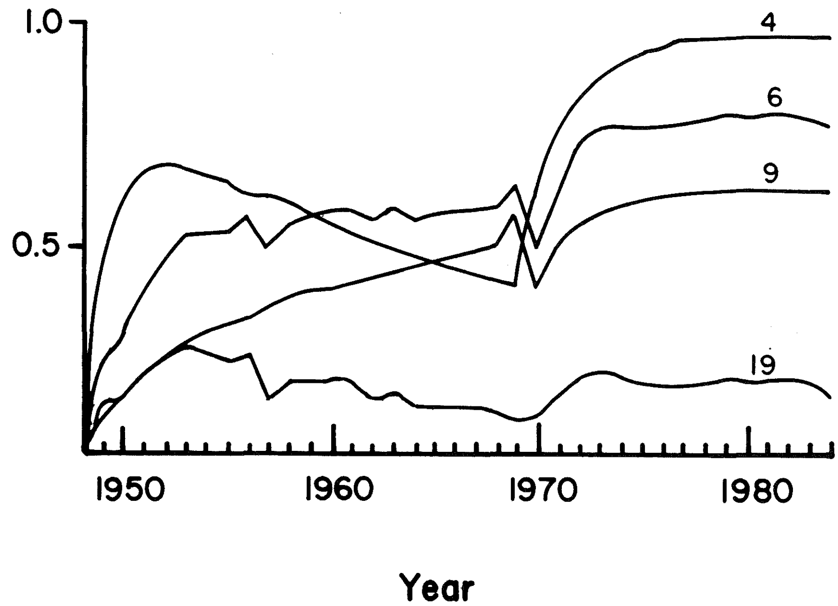


Figure 31. Simulated yield by number (gilled and creeled) and vulnerable population size, Lake of the Woods, Minnesota. Simulated recruitment was constant with 125 million fry each year during 1949-1965 and 200 million fry each year during 1966-1984. Age-specific angling catchability was increased by 75% for the period 1949-1970. Trends are identified and scaled as follows:
4 = number of fish in the population age 5 and older/1,000,000 (maximum = 962,100);
6 = total number gilled and creeled/600,000 (maximum = 466,400)
9 = number creeled/600,000 (maximum = 364,670);
19 = number gilled/600,000 (maximum = 147,370).

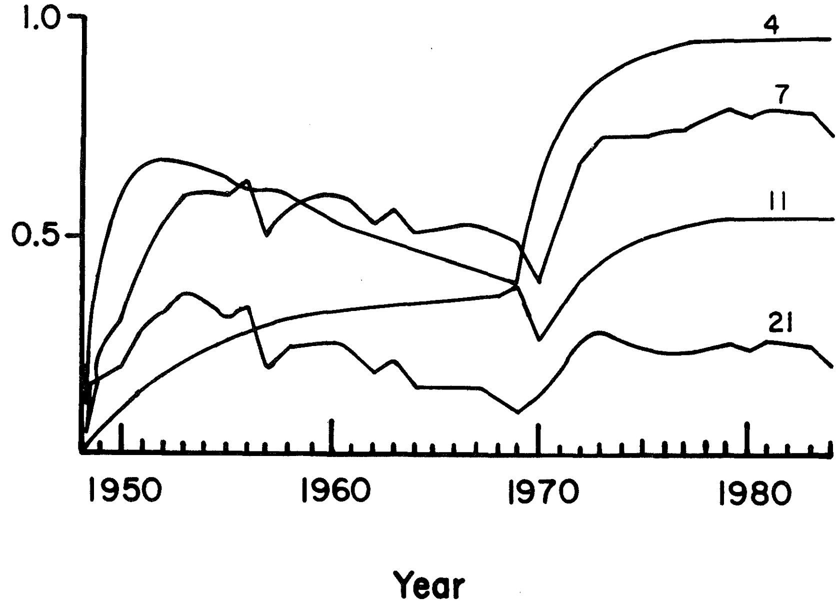


Figure 32. Simulated yield in weight (pounds gilled and creeled) and adult population size, Lake of the Woods, Minnesota. Simulated recruitment was constant with 125 million fry each year during 1949-1965 and 200 million fry each year during 1966-1984. Age-specific and angling catchability was increased by 75% for the period 1949-1970. Trends are identified and scaled as follows:
4 = number of fish in the population age 5 and older/1,000,000 (maximum = 962,100);
7 = weight gilled and creeled/800,000 pounds (maximum = 633,300 lb);
11 = weight creeled/800,000 pounds (maximum = 429,100 lb);
21 = weight gilled/800,000 lb (maximum = 294,750 lb).

of walleye over 16in TL in assessment nets between the periods 1968-70 and 1980-84. Local bait stores running annual fishing contests also reported many more large walleye ($\geq$5 lb) caught during the 1980s (Schupp 1981).

As expected, simulated sport fishing yield was greater than estimated yield during most of the time series. Annual harvest in numbers creeled by anglers was constant at 80% of the total number landed since about 1962 (Fig. 31). Yield in biomass was greater for the commercial gill netters until 1957 when anglers creeled an increasing majority of total yield until 1969 (Fig. 32). Biomass taken by anglers stabilized at about 70% of the total yield after 1972.

Simulated angling was compared with creel surveys from 1968-70 (Schupp 1974) and from 1982-84. Simulated age composition in the creel was much less variable (Table 27) because of the assumption of constant recruitment. More larger walleye are in the simulated 1982-84 creel because of increased escapement from reduced gill net effort during the last 10 years. Age 2 walleye were not catchable in the simulations.

Although the model predicted greater than actual numbers creeled and gilled, the percentages of the total caught by each group were similar (Table 28). Simulated weight creeled by anglers is lower than the actual during 1968-70 but higher than the actual during 1982-84.

Varying the number of fry under the assumptions of constant recruitment and catchability scales catches without changing the trends. To a much lesser extent the trends can be scaled upward or downward by changing the proportion of tags reported after being caught from the commercial and sport fisheries in 1982. Estimates of RC = 0.9 and RS = 0.5 were used when the trends shown in the figures were generated (line 130).

Table 27. Comparison of simulated percent-by-age in the creel (in parentheses) to actual estimates provided by Schupp (1985, personal communication). Length frequencies were converted to age frequencies via age-length keys (Appendix F).

	Age											
Year	2	3	4	5	6	7	8	9	10	11	12	13
1968	2.4	0.3	23.8	56.2	8.6	6.8	1.4	0.3	0.2			
		(23.9	26.5	28.3	12.3	5.1	2.2	0.9	0.4	0.2	0.1	0.1)
1969		26.1	0.7	23.8	34.7	7.1	6.1	0.8	0.3	0.3		
		(33.9	23.1	24.7	10.6	4.4	1.8	0.8	0.3	0.2	0.1	0.1)
1970		0.9	74.3	3.4	7.1	7.6	4.6	1.7	0.5			
		(29.6	32.6	21.7	9.4	3.8	1.6	0.7	0.3	0.1	0.1	0.1)
Ave.	1.0	8.1	32.4	30.5	15.9	7.1	3.8	0.8	0.3	0.1		
		(29.2	27.4	24.9	10.8	4.4	1.9	0.8	0.3	0.1	0.1	0.1)
1981[a]	0.7	26.6	20.9	40.2	7.2	3.4	0.7	0.1	0.0	0.1	0.1	
1981[b]	11.0	41.9	18.0	21.5	5.4	2.0	0.0	0.2				
1981[a+b]	2.0	28.5	20.5	37.8	6.9	3.3	0.7	0.1	0.1	0.1	0.1	
		(19.0	23.1	28.4	14.9	7.4	3.7	1.8	0.9	0.5	0.2	0.1)
1982[a]	2.1	20.6	48.2	11.4	13.1	3.4	1.0	0.1	0.1			
		(19.0	23.1	28.4	14.9	7.4	3.7	1.8	0.9	0.5	0.2	0.1)
1983[b]	8.8	22.3	35.0	21.9	3.5	5.6	2.0	0.6	0.2			
		(19.0	23.1	28.4	14.9	7.4	3.7	1.8	0.9	0.5	0.2	0.1)
1984[a]	2.0	31.5	19.9	30.4	10.3	3.0	2.1	0.4	0.1	0.2	0.0	0.1
1984[b]	11.7	38.3	19.3	19.9	5.3	2.6	1.6	1.2	0.1			
1984[a+b]	3.2	32.3	19.8	29.0	9.7	3.0	2.0	0.5	0.2	0.2	0.1	0.1
		(19.0	23.1	28.4	14.9	7.4	3.7	1.8	0.9	0.5	0.2	0.1)
Ave.	2.4	27.1	29.5	26.1	9.9	3.2	1.2	0.2	0.1	0.1	0.1	0.1
		(19.0	23.1	28.4	14.9	7.4	3.7	1.8	0.9	0.5	0.2	0.1)

[a] Length samples were collected during 15 May-15 August.
[b] Length samples were collected during 16 August-20 October.

Table 28. Comparison of yearly simulated yield (in parentheses) to actual estimates. Percentage of total yield is below the numbers.

Period	Numbers: Gill net	Angling	Total
		Number	
1968-1970	38,225 (47,035)	282,837 (286,630)	321,062 (333,665)
	11.9 (14.1)	88.1 (85.9)	100 (100)
1982-1984	77,631 (91,543)	325,189 (363,088)	402,819 (454,631)
	19.3 (20.1)	80.7 (79.9)	100 (100)
		Weight	
1968-1970	76,449 (94,070)	333,296 (271,326)	409,745 (365,397)
	18.7 (25.7)	81.3 (74.3)	100 (100)
1982-1984	155,262 (183,086)	340,880 (426,482)	496,142 (609,568)
	31.3 (30.0)	68.7 (70.0)	100 (100)

Projection of Trends

The final version of the simulation model was modified to begin in 1970 (Users Guide). As a result, the model was simplified because current values for the amount of fry produced and catchability could be used. Also, length of the trends were the same as in the previous section (36 years).

A baseline scenario of commercial fishing effort, held constant at the 1984 level after 1984, angling pressure increasing at a rate similar to the past 15 years and constant instantaneous angling mortality at the 1970 level (simulating reduction in angling efficiency with increased mh) was used. Under this scenario, the model showed a stable fishery for the next 20 years (Fig. 33). The model assumed constant recruitment each year and constant size-specific catchabilities as determined from the 1982 tagging study. It is important to note that the projected trends could fluctuate in magnitude similar to the actual trends.

Figure 33. Projections with commercial fishing effort constant during 1984-2005, Lake of the Woods, Minnesota. For the entire simulation, recruitment was constant with 200 million fry each year and age-specific catchability was constant at the estimates obtained from the tagging study in 1982.

Figure 33a. Projection of yield in weight (pounds gilled and creeled) and adult population size (dashed line). Trends are identified and scaled as follows:

4 = number of fish in the population age 5 and older/1.176E6 (maximum = 980,600);
7 = weight gilled and creeled/800,000 lb (maximum = 633,240 lb);
11 = weight creeled/800,000 lb (maximum = 445,980 lb);
21 = weight gilled/800,000 lb (maximum = 228,660 lb).

Figure 33b. Projection of the walleye angling fishery. Trends are identified and scaled as follows:

9 = number creeled/500,000 (maximum = 371,100);
13 = mh/1.4 E6 (maximum = 1,078,750);
14 = number caught per mh/1 maximum = 0.83);
15 = number creeled per mh/1 (maximum = 0.49);
17 = mean length in catch/16in (maximum = 13.5in);
18 = mean length in creel/16in (maximum = 14.8 in).

Figure 33a

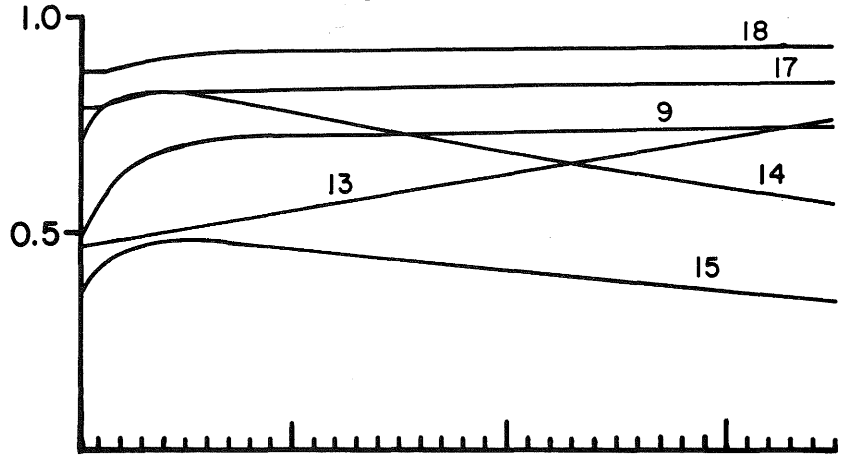
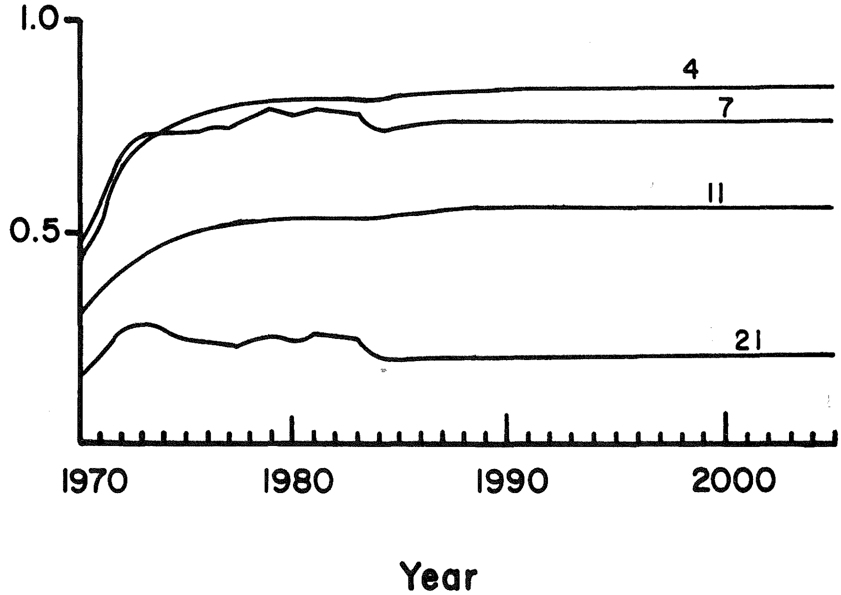


Figure 33b



The model predicted that, under the assumption of no commercial fishing after 1984, the average size of walleye in the creel would increase from 14.8in (1.0 lb) to 15.2in (1.2 lb) (Fig. 34). Number creeled would increase from 364,700 in 1984 to 410,000 by 1992. The creel rate increased only slightly and then declined as fishing pressure (mh) continued to increase. Because walleye in commercial size-classes have low catchabilities to anglers, the number of adults in the population increased from 947,600 in 1984 to 1,113,500 by 1989 and total yield declined from 443,550 (586,870 lb) in 1984 to 410,000 (543,450 lb) by 1992. Thus, a harvestable surplus of about 33,550 fish (43,420 lb) remained in the lake.

Under the assumption that angling pressure did not increase after 1984, the model predicted a decline in creel rate but no increase in the average size of walleye in the creel (Fig. 35). Size-specific catchabilities stayed in the same relative proportion to each other regardless of angling pressure. This made a goal of an 18.5in (2 lb) walleye in the creel impossible to obtain if anglers continued to creel the relatively easier to catch smaller size classes.

Minimum, maximum and slot length limits were compared from 1984-2005 (Fig. 36). Minimum limits allowed creeled fish above the specified length, maximum limits creeled fish below a specified length and slot limits creeled fish outside a range delimited by specified lengths (window limits allowed creeled fish inside a range specified). Instantaneous hooking mortality rates used were 0.29 (annual rate = 25%) for ages 3 and 4 and 0.10 (annual rate = 10%) for ages 5-16 (line 210).

Slot limits caused the largest increases in mean length in the catch but the maximum change expected was only 0.5in (Fig. 36a). Minimum size limits increased mean length in the creel (Fig. 36b). The model predicted that a

Figure 34. Projections with no commercial fishing during 1985-2005, Lake of the Woods, Minnesota. For the entire simulation, recruitment was constant with 200 million fry each year and age-specific catchability was constant at the estimates obtained from the tagging study in 1982.

Figure 34a. Projection of the walleye angling fishery. Trends are identified and scaled as follows:
9 = number creeled/500,000 (maximum = 410,600);
13 = mh/1.4 E6 (maximum = 1,078,750);
14 = number caught per mh/1 (maximum = 0.83);
15 = number creeled per mh/1 (maximum = 0.49);
17 = mean length in catch/16in (maximum = 13.9in);
18 = mean length in creel/16in (maximum = 15.2in).

Figure 34b. Projection of walleye yield in weight (pounds gilled and creeled) and adult population size (dashed line), Lake of the Woods, Minnesota. Trends are identified and scaled as follows:
4 = number of fish in the population age 5 and older/1.17E6 (maximum = 1,141,880);
7 = weight gilled and creeled/800,000 lb (maximum = 633,270 pounds);
11 = weight creeled/800,000 lb (maximum = 546,580 lb);
21 = weight gilled/800,000 lb (maximum = 228,660 lb).

Figure 34a

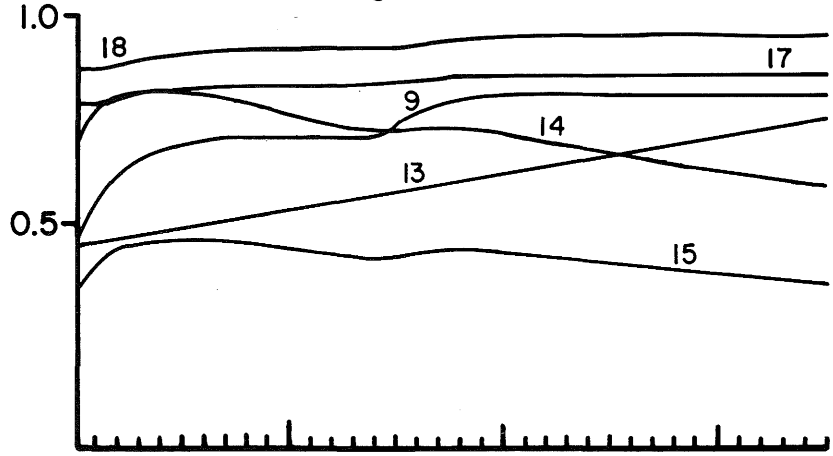


Figure 34b

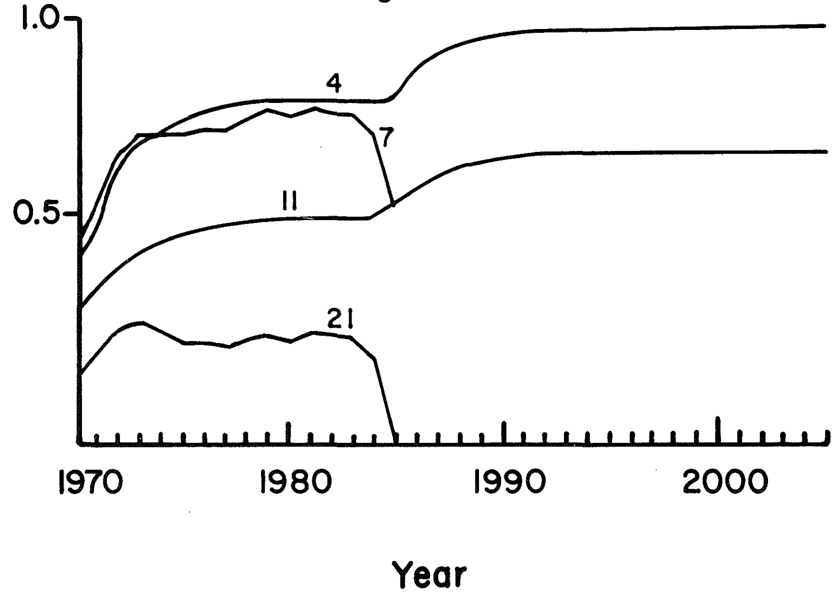


Figure 35. Projections with constant angler-hours during 1984-2005, Lake of the Woods, Minnesota. For the entire simulation, recruitment was constant with 200 million fry each year and age-specific catchability was constant at the estimates obtained from the tagging study in 1982.

Figure 35a. Projection of the walleye angling fishery. Trends are identified and scaled as follows:
9 = number creeled/500,000 (maximum = 410,630);
13 = mh/1.4 E6 (maximum = 831,200);
14 = number caught per mh/1 (maximum = 0.83);
15 = number creeled per mh/1 (maximum = 0.49);
17 = mean length in catch/16in (maximum = 13.9in);
18 = mean length in creel/16in (maximum = 15.2in).

Figure 35b. Projection of walleye yield in weight (pounds gilled and creeled) and adult population size (dashed line), Lake of the Woods, Minnesota. Trends are identified and scaled as follows:
4 = number of fish in the population age 5 and older/1.17E6 (maximum = 1,141,880);
7 = weight gilled and creeled/800,000 lb (maximum = 633,240 lb);
11 = weight creeled/800,000 lb (maximum 546,580 lb);
21 = weight gilled/800,000 lb (maximum = 228,660 lb).

Figure 35 a

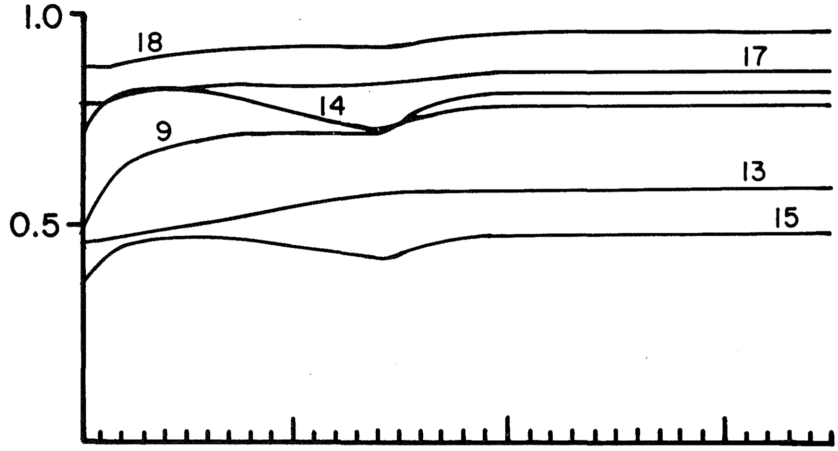


Figure 35 b

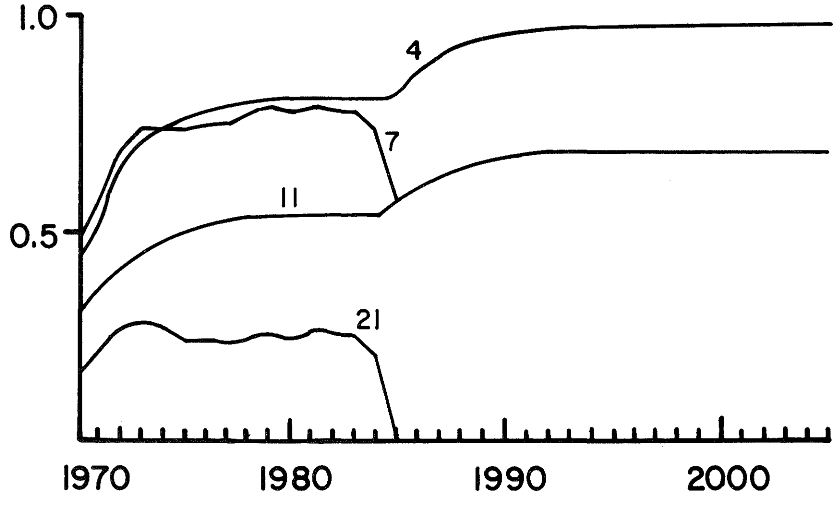


Figure 36. Projections of indicator variables under different length regulations for walleye, Lake of the Woods, Minnesota. No commercial fishing and steadily increasing angling pressure occurred during 1985-2005. For the entire simulation, recruitment was constant with 200 million fry each year and age-specific catchability was constant at the estimates obtained from the tagging study in 1982.

1) no length limit
2) minimum of 13 inches
3) minimum of 14 inches
4) minimum of 16 inches
5) maximum of 20 inches
6) protected slot of 15-18 inches
7) protected slot of 16-20 inches

Figure 36a. Average length (in) in the angler's catch.

Year	Scenario number 1	Scenario number 6,7
1984	13.5	13.5
1985	13.5	13.6
1990	13.8	14.4
2005	13.9	14.5

Figure 36b. Average length (in) in the angler's creel.

Year	Scenario number 1	2	3	4
1984	14.8	14.8	14.8	14.8
1985	14.8	15.5	16.1	17.4
1990	15.2	15.9	16.4	17.8
2005	15.2	15.9	16.5	18.0

Figure 36c. Catch per manhour.

Year	Scenario number 1	Scenario number 4
1984	0.73	0.73
1985	0.74	0.76
1990	0.73	0.85
2005	0.61	0.71

Figure 36d. Number creeled per manhour.

Year	Scenario number 1	2,5	6,7	4
1984	0.44	0.44	0.44	0.44
1985	0.45	0.38	0.30	0.18
1990	0.45	0.41	0.33	0.27
2005	0.38	0.34	0.28	0.24

Figure 36e. Yield (no).

Year	Scenario number 1	2,5	6,7	4
1984	443,550	443,550	443,550	443,550
1985	375,700	318,800	249,000	154,700
1990	408,770	367,700	296,800	246,700
2005	410,600	370,900	304,100	254,550

Figure 36f. Yield (lb).

Year	Scenario number 1	4	5	6
1984	586,870	586,870	586,870	586,870
1985	448,350	286,100	378,070	243,800
1990	536,570	492,460	419,150	407,104
2005	546,580	529,900	419,150	446,170

Figure 36 a

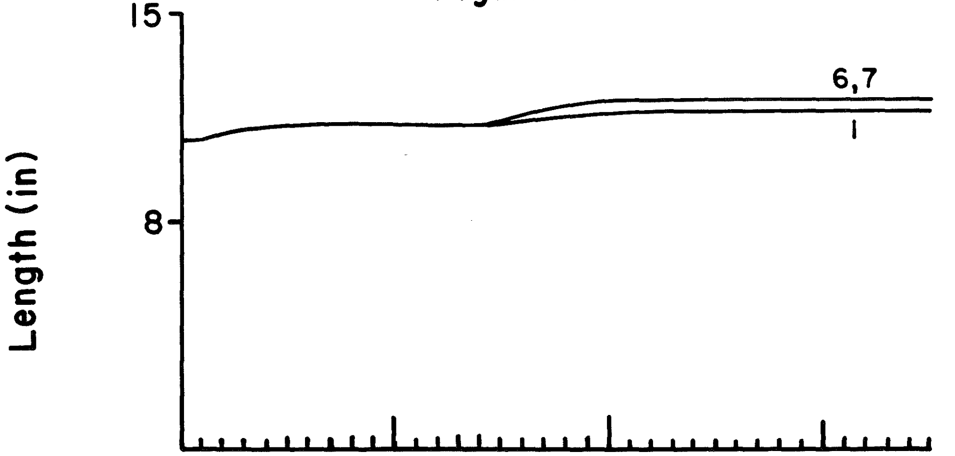


Figure 36 b

Figure 36 c

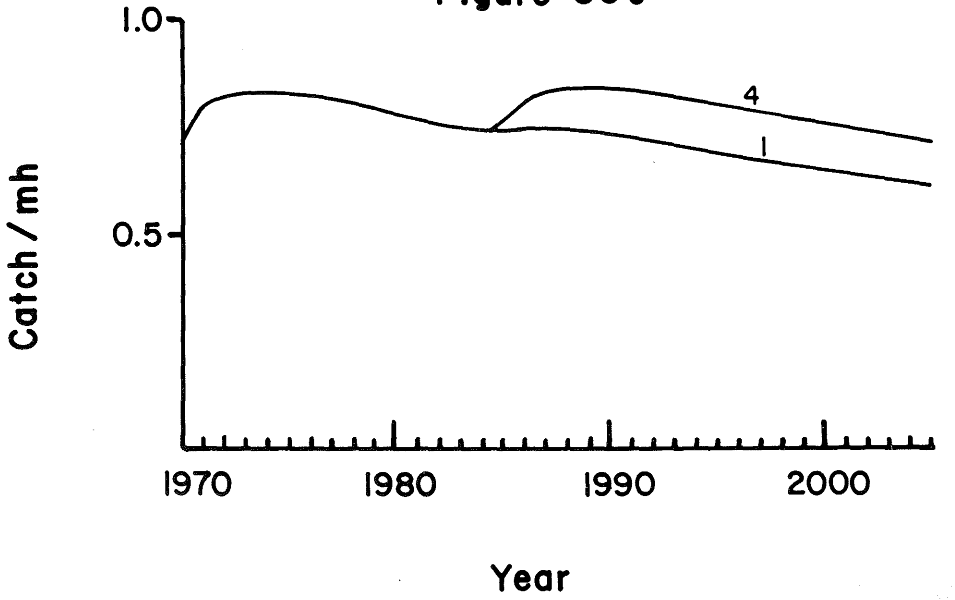


Figure 36d

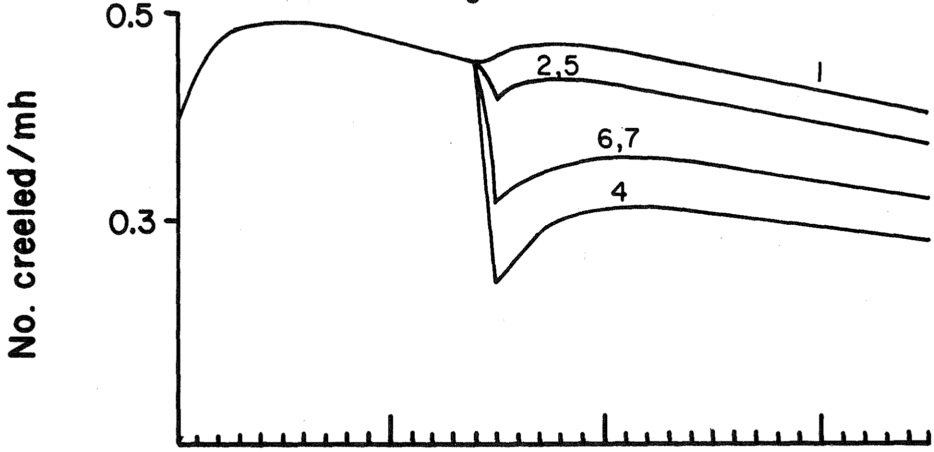


Figure 36e

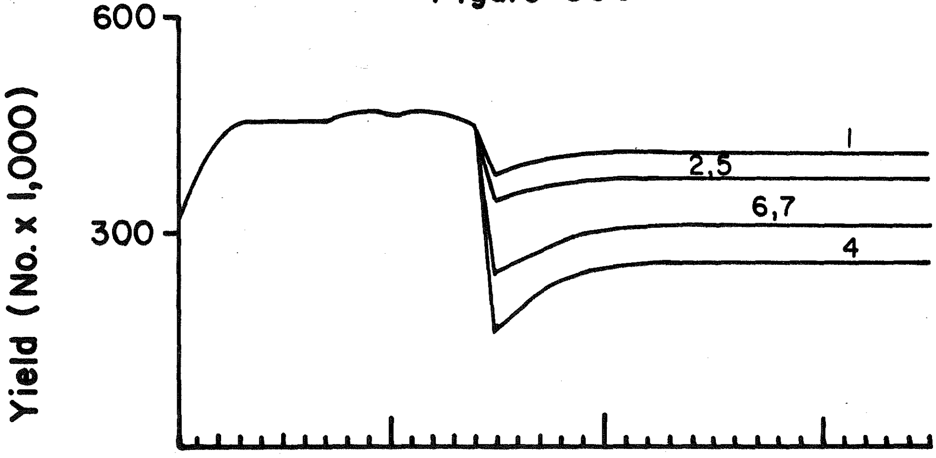
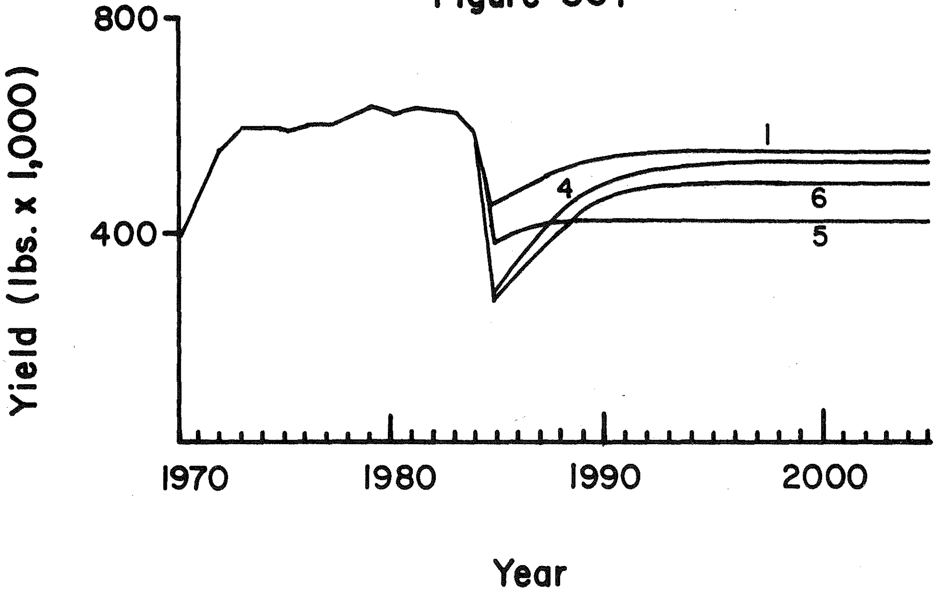


Figure 36f



2.0 lb average could be obtained with a minimum size limit of 16in, and a 1.5 lb average with a 14in minimum size limit. Only the 16in minimum size regulation out-performed slot limits for increasing the catch rate (Fig. 36c) but the maximum increase was 0.10 walleye per mh. The creel rate declined with every creel restriction (Fig. 36d) because recruitment was unaffected in the model. The decline in creel rate was the converse of the increase in catch rate. The 16in minimum size limit decreased the creel rate by 0.15 walleye per mh (Fig. 36d) and the yield in numbers by almost 200,000 walleye (Fig. 36e) but yield in weight declined by only 57,000 lb (Fig. 36f) because of improved size in the creel. The 20in maximum size limit was comparable to the 13in minimum size limit for numbers creeled by the angler (Fig. 36e) but the yield in weight was 130,500 lb less (Fig. 36f).

Creel limits also were not addressed in the model. Precise estimates of walleye caught and released but killed by hooking mortality compared to those creeled are not available for large lakes. Current effort applied to creel census is not adequate to obtain small enough confidence intervals so that differences caused by the regulation change can be measured. Modeling creel limit effects without good estimates would give false impressions of the utility of creel limits.

DISCUSSION

The community composition of the Lake of the Woods fishery has remained stable over the past 15 years. Variations in relative abundances and CPUEs for individual species occurred in response to changing year-class strengths and exploitation rates but no major trends were apparent. The absence of an exceptionally large year-class of cisco such as that recruiting to assessment nets in 1969 and 1970 (Schupp 1974), combined with an increase in yellow perch abundance since that time, have resulted in a slight decline in overall

CPUE and an increase in the relative contribution of percids to assessment gear. The percid component in the lake has generally remained between 62% and 72% since the 1930's (Schupp and Macins 1977). The brief occurrence of rainbow trout in assessment nets was an anomaly resulting from a single stocking and the reoccurrence of this species is not expected. Northern pike and walleye preyed on the rainbow trout and both cisco and trout suffered a summerkill when water temperatures exceeded 74 F in 1983 (M.L. Larson, MN Dept. Nat. Res., personal communication 1985).

Seasonal variations in assessment net catches reflected fluctuations in the abundance and habits of individual species and were similar, though not as marked, to those in 1968-70 (Schupp 1974). Increased catches of walleye in fall netting can be partially explained by the continuing recruitment of several strong year-classes to the gear and the typical inshore movement demonstrated by this species as water temperatures decline and an increased forage base is sought. Peak catches of walleye in the fall have previously been documented for the Lake of the Woods commercial fishery (Carlander 1942) and for sport catches from other major walleye lakes (Schupp 1972). Increased mobility of older, larger walleye during fall months was noted by Smith and Ney (1973) for Red Lake.

Elevated catches at depths exceeding 20 ft were dominated by and reflected the general habitat preferences of commercially harvested species. The more equitable distribution of walleye over all sampling depths indicated a more balanced population supported by multiple year-classes and increased numbers of walleye in sets $\geq$15 ft may reflect the increased abundance and behavioral characteristics of larger fish. The relative abundance of walleye $\leq$16in was less during the current study than in 1968-70 (Schupp 1974) but recruitment of the 1966 year-class to the gear inflated relative values from the previous period. The increased abundance of larger walleye and their higher survival rates through reduction of commercial harvest also explains the decline in relative, though not necessarily absolute, abundance of smaller fish during the present study.

The increase in open-water fishing effort on Lake of the Woods by Minnesota-based anglers over the past 15 years has been characterized almost exclusively by a shift towards Canadian waters. This shift is partially in response to the use of higher quality fishing craft allowing quicker and safer access to Ontario and Manitoba waters of the lake, the removal of commercial pound nets from the Springsteel-Buffalo Point area and the conviction that Canadian waters provide better fishing. The shallow, productive habitat of Manitoba waters and the islands and reefs of Ontario also serve to concentrate fish and offer protection from adverse weather conditions which expands fishing opportunities and increases CPUE compared to the open expanses of the Big Traverse. The reduction of non-resident creel limits by Ontario, the recognition of only a single limit from border waters by Minnesota and the highly publicized conflicts between sport and commercial fishery interests may have concurrently led to a perception of deteriorating angling on the east side of the lake and contributed to shifting effort away from the Rainy River area.

Walleye angling on Lake of the Woods followed a typical pattern of effort being generally concentrated during the first six weeks of the season. Total effort generated by Minnesota-based anglers and effort near the mouth of the Rainy River and along the south shore of the lake approach or exceed levels on other major walleye lakes in Minnesota (Schupp 1972; Strand 1980; Osborn and Schupp 1985) and continues to be moderate to heavy on those areas most frequented by anglers. As pointed out by Schupp (1974), comparisons of mh/A on Lake of the Woods to those from other large lakes having effort more evenly dispersed is of limited value.

Walleye continue to be the primary species of interest to anglers, with yellow perch, sauger and northern pike complementing the open-water creel. Though walleye CPUE has declined since 1968-70 (Schupp 1974), the 0.35 fish/mh estimated for Minnesota waters of the lake is substantially higher than the 0.17-0.23/mh documented over a similar time period for other major walleye lakes in Minnesota (D.H. Schupp, MN Dept. Nat. Res., personal communication 1985; Osborn and Schupp 1985; Schupp 1972; Strand 1980; Ernst and Osborn 1980). The overall decline in CPUE on Lake of the Woods is primarily due to declining catch rates for walleye which accounted for 84% of the harvest but CPUE for the three other principal sport species in the open-water harvest also declined over the same time period.

The total harvest of walleye by open-water anglers was comparable to that from 1968-70 (Schupp 1974). Increased harvests from Canadian waters corresponded to large increases in effort which eclipsed the influence of decreasing CPUE. Harvests from American waters declined because a similar decrease in CPUE occurred at levels of effort constant with those from 1968-70 (Schupp 1974). The largest decline in CPUE occurred in Manitoba waters which incurred the largest increase in effort while the smallest decline occurred on the Rainy River where pressure actually declined.

Anglers fishing inshore areas primarily harvested 3 to 5 year old walleye because older, larger walleye frequent offshore areas during summer months to feed on cisco and crayfish. Age 3-5 walleye were represented by two strong year-classes during each of the three creel survey years in the present study. Approximately twice the number of walleye age 5 or less were harvested in this study than in 1968-70 (Schupp 1974) which to a large extent explains the slight decline in average weight of creeled walleye. The tendency of anglers to fish inshore areas and use techniques targeting smaller fish, the relatively large numbers of smaller fish available from several strong year-classes and the acceptance of these smaller fish in the creel reduced the average size harvested and dampened any general trend towards larger fish in the creel. A substantial increase in the number of larger walleye creeled did occur but was not perceived by anglers due to the distribution of these fish among an increasing number of harvesters. The recent increase in trolling offshore areas and the allowance of two lines while trolling may increase CPUE and average size in the creel to a limited extent dependent on the number of anglers adopting this technique.

The increased effectiveness of small boat/pleasure craft anglers is supported by their catch rates being more similar to those from launches, which historically have had the highest catch rates. The use of higher quality craft and more sophisticated equipment is largely responsible for this change. Relative use of launches and small boats/pleasure craft has remained consistent and is comparable to that from other large walleye lakes (Osborn and Schupp 1985).

Sauger and yellow perch make up a substantial part of the biomass in Minnesota waters of the lake but continue to be underutilized in the open-water fishery. It appears that anglers are now beginning to accept sauger more readily in the creel, particularly in the winter fishery. The presence of grubs (Clinostinum spp.) in yellow perch from the weedy areas of the Big Traverse have caused them to be generally unaccepted in the creel but parasite-free yellow perch from weedless areas make an excellent food fish. The status of the northern pike population has remained constant and will probably remain so as long as their harvest continues to be incidental to that for walleye.

The large increase in winter sport effort and harvest seen over the past 15 years in Minnesota waters is primarily a result of increased sauger abundance and their acceptance in the creel and to resort owners providing access to winter fishing areas. A 9-fold increase in both effort and CPUE resulted in a 100-fold increase in sauger harvest. CPUE for walleye has remained constant over the same time period and while the walleye harvest increased, it was not of the same magnitude as that for sauger and contributed only about 11% to the annual sport harvest. The winter fishery is variable and continued evaluation is needed to determine whether the 1982-83 season was an exception or if the trend towards increased effort and harvest will continue. The winter fishery in 1982-83 contributed substantially to annual sport effort and since the focus was almost entirely on Minnesota waters, served to reverse the overall shift in effort to Canadian waters seen in the open-water fishery.

Mortality estimates based on catch curves of walleye sampled in assessment gill nets are sensitive to both behavior of the fish and the selectivity of the gear (Hamley and Regier 1973). In the present study, walleye may have been less vulnerable to assessment nets due to both gear selectivity and their movements to offshore locations during summer months. High estimates of mortality derived from volunteer tag returns are probably not entirely due to tag-induced mortality. Post-study discussions with cooperators disclosed that enthusiasm for voluntary return of tags decreased following the first year of study. Only one of three tags found by anglers on a portage in the Boundary Waters Canoe Area, some 300 mi from Lake of the Woods, had been reported by a commercial fisherman.

The reporting rates derived for both the sport and commercial fisheries are sensitive to a number of factors. The commercial reporting rate is affected by the estimate of population size. Since the main assumptions revolve around a closed population, it is reasonable to assume that the population estimates derived by the stratified or standard Peterson methods are underestimates primarily due to dilution of marked fish by mortality and emigration into Canadian waters. Increasing the estimate of population size would result in a higher reporting rate by commercial fishermen but a lower rate by anglers. As stated earlier, assuming a Z of 0.80, our estimates of Rc of 0.68 and Rf of 0.45 may be reasonable. Schainost (1983) estimated angler reporting rates for walleye as 0.70 in Nebraska. Rawstrom (1971) reports that reporting rates from California anglers ranged from 0.50 to 0.70 for a variety of species and suggested using 0.60 as a general rule. Rate of reporting will certainly be influenced by the disposition of the user group and their relationship with the resource agency.

Commercial harvest of tagged walleye from Lake of the Woods was compared to that from the Red Lakes, Minnesota (Smith et al. 1952). A larger size of maximum vulnerability in the Lake of the Woods commercial fishery may be directly attributed to the 4-inch mesh gill nets used compared to the 3.5-inch mesh used on the Red Lakes. In both fisheries, females showed a decrease in vulnerability after peak recruitment. Males on Lake of the Woods showed a leveling off of size-specific exploitation in the commercial gear at an approximate total length of 19in. Similarly, Smith et al. (1952) reported that males remained completely vulnerable to the commercial nets after reaching maturity. It was also reported by commercial fishermen on Lake of the Woods that some walleye, especially those of smaller size, were entangled in the mesh by the disc dangler tag. Estimates of commercial exploitation of smaller fish from tag returns should therefore be considered with some caution.

Typical indications of an over-exploited stock were not evident during the present study. Growth rates, ages and sizes at maturity, fecundity and mortality rates for walleye in Minnesota waters of Lake of the Woods were comparable to those from the 1940's (Carlander 1942) and 1960's (Schupp 1974). This compares to heavily exploited Shoal Lake where 80% of the spawning stock in 1985 was from one year-class, two-year-old males and four-year-old females were found to be mature and growth rates were considerably higher than those from previous years (Lockhart et al. 1985). Ages of recruitment to both the commercial and sport fisheries on Lake of the Woods were also comparable to previous studies. Although females continue to be exposed to one or two years of commercial and three or four years of sport exploitation before initially spawning, there were no indications that natural reproduction was affected or limited the population.

The walleye population in Minnesota waters of Lake of the Woods has improved markedly over the past 15 years and is now characterized by relatively stable year-class strength and a fishery supported by five or six strong year-classes. The general improvement and existing stability initially evolved from the recruitment of the extraordinarily large 1966 year-class to both the spawning stock and the fishery in the 1970's after which natural reproduction improved considerably and commercial CPUEs were elevated to levels consistently higher than in previous years.

The potential yield of walleye from Minnesota waters of Lake of the Woods based on the MEI and yield percentages from stable walleye fisheries undergoing heavy angling effort was estimated to be 430,100 lb (Ontario Min. Nat. Res. and MN Dept. Nat. Res. 1984). This yield level was exceeded only three times between 1937 and 1973 and has not been exceeded in recent years.

Total walleye harvest during the present study period was comparable to that documented by Burrows (1951) when the harvest was essentially all commercial and to 1968-70 levels (Schupp 1974) when the sport fishery dominated the harvest. The sport fishery continued to account for the major proportion of the harvest in the present study though commercial harvest had doubled since 1968-70 (Schupp 1974). The increased commercial harvest resulted from the increased number of larger walleye elevating the CPUE and would probably have been higher in 1984 had the harvest quota not been in effect. The commercial harvest exceeded the sport harvest only for age 7 and older walleye and data from the present study shows that relative abundance of walleye on Lake of the Woods was not related to the commercial fishery in recent years.

The anticipated removal of the commercial fishery from Lake of the Woods should result in increased abundance of larger walleye but potential increases in natural mortality rates and decreased growth rates for younger fish may buffer the increased harvest of these fish by the sport fishery. The shift in walleye biomass to older, larger fish and possible changes in biomass allocation among other species should be monitored upon cessation of the commercial fishery. Changes in biomass of individual species previously harvested by the commercial fishery may be more affected by year-class strength than a reduction of harvest. Many large walleye lakes having similar species compositions and on which no commercial fishery exists currently exhibit desirable community structures and stability. The removal of a commercial fishery which has acted constantly on a community for a hundred years, however, presents a unique opportunity to evaluate potential changes.

Authors of previous studies on Lake of the Woods have indicated that the maintenance of a controlled commercial fishery to regulate competitive species was desirable and the only economical means to harvest species not taken by anglers (Burrows 1951; Schupp and Macins 1977). The population structure and catchability of walleye in large lakes has been shown to be more dependent on fluctuations in year-class strength and abundance of forage fish than on fishing effort (Forney 1980; Serns and Kempinger 1981). Walleye fisheries in large lakes seem to be characterized by relatively low vulnerability of older fish, therefore failures in recruitment from depleted spawning stocks have not been reported in such angling fisheries. The fish population of Escanaba Lake, Wisconsin, was not depleted after 20 years of liberalized regulation (Kempinger et al. 1975). Analysis from the present study indicates that the relative abundance of walleye in Lake of the Woods was not related to the commercial fishery.

The simulation model was designed to show the relative impacts of different management scenarios on the walleye population and fishery of the Minnesota waters of Lake of the Woods and to provide possible explanations for trends in commercial and angling catch rates. The model also provides an aid in conceptualizing management plans and reveals gaps in the understanding and/or availability of data.

Model predictions, assuming no commercial fishery after 1984, show angler effort increasing at levels constant with the past 15 years. Constant size-specific catchabilities seem to most realistically represent the present situation on Minnesota waters of Lake of the Woods. Under this scenario, the model predicted an increase in the number of creeled walleye, an increase in average size, an initial increase in CPUE followed by a decline with increasing effort and a decline in total yield. This sequence suggests that a harvestable surplus of approximately 43,000 lb of walleye would be available in Minnesota waters. The model predicted a stable fishery over the next 20 years which appears realistic in light of the present status of the stocks.

The model presently has no density-dependent mortality function for pre-recruits. The assumption of constant recruitment until age 3 created a simulated increase in recruitment from fry stocking. Large scale fry stocking in Lake of the Woods in the 1920's and 1930's (Carlander 1942) were not correlated with year-class strength and the use of stocking in the model would result in unrealistic values.

The model showed that commercial fishing effort could predict yield since 1940 and that variations from the predicted yields were random rather than systematic. Trends were reasonable when constant growth and recruitment were assumed, indicating that realistic variations from the average were probably random and not related to fishing pressure. The fishery had become less efficient in recent years because of the decline in commercial fishing effort (Schupp 1981). Walleye were not vulnerable enough to anglers to cause serious failures in recruitment.

Catches grew linearly with increasing numbers of fry because one unit of fishing effort removed a constant proportion of each age-class. Natural mortality remained constant for ages 3-16 and fishing mortality varied linearly with fishing effort. This sensitivity can be reduced by incorporating density-dependent natural mortality on ages 0-2 and/or using a function to predict catchability from the amount of fishing pressure, changes in fishing technology and the amount of forage available.

Creel limits were not addressed in the model because precise hooking mortality information is lacking and current data from creel surveys are not adequate to obtain small enough confidence intervals to determine differences caused by regulation changes. Catch-sharing among anglers in a single boat would also diminish the effect of a bag limit reduction since a smaller proportion of boat parties fill limits than do individual anglers. Only 15% of all anglers on Lake of the Woods creeled their limit in one trip during the present study.

Lake of the Woods is similar to Escanaba Lake (Kempinger and Carline 1977; Serns and Kempinger 1981) and Oneida Lake (Forney 1980) in that exploitation rate is not related to walleye density or to angling effort. This makes the application of a length limit in the model somewhat unpredictable because factors which affect catchability such as forage fish abundance and distribution, fishing technology and number of windy days will mask the effects of the limit. Annual recruitment to the commercial fishery in Red Lakes depended on growth during the fishing season rather than on abundance of pre-recruits of younger age-classes and fishing intensity did not cause major changes in yield of subsequent seasons (Smith 1977). For minimum size limits to be effective for increasing recruitment, growth must be independent of year-class strength, otherwise large, slower growing year-classes will linger at sizes below the limit (Serns 1978). Even then improved catches above the minimum size may not be caused by the regulation but rather by timely recruitment of consecutive strong year-classes (Serns 1981).

Changes in recruitment, growth and natural mortality as a result of length regulations cannot occur in the model because these processes are assumed constant. Simulated changes therefore result directly from the length regulations. The present model is essentially a numerical version of Ricker's analytical model of yield per recruit (Schneider 1978) but provides more description of the population parameters. For average sport walleye fisheries in Michigan (Schneider 1978), a change in the minimum size limit from 13 to 15in caused: 1) little change in yield; 2) a 15-20% increase in walleye caught; 3) a 10-25% decrease in creeled walleye; and 4) a 10-25% increase in the biomass of the population. From the present study for the Lake of the Woods angling walleye fishery, the model predicted a change in the minimum length limit from 13 to 15in would cause: 1) little change in yield; 2) an 8% increase in walleye caught 3) a 20% decrease in creeled walleye; and 4) a 16% increase in the biomass of the population age 5 and older.

The open, unstructured Big Traverse area of Lake of the Woods probably harbors about 1 million adult walleye and extremely abundant forage such as tullibee, yellow perch, emerald shiners, aquatic insects and crayfish. The relatively low catchability of larger walleye utilizing this area causes no increase in angler catch rates in the model in spite of above average year-class strength, growth rates and reduced commercial fishing effort. After commercial fishing is terminated, over 40,000 lb of walleye are predicted to remain unutilized in the lake although fishing effort will increase each year. If recruitment continues at a rate similar to the last 10 years, mean size in the creel will probably remain at about 15in because of the extreme abundance of young walleye recruiting at smaller sizes which are apparently acceptable to most anglers.

MANAGEMENT IMPLICATIONS

Lake of the Woods has shown a positive community response since the late 1960s. In order to continue to manage this lake for optimum sport fishing benefits, the following work should be continued or initiated:

1. Continue the assessment netting for all species of fish;
2. Continue the non-uniform probability creel census at least two consecutive years out of five;

3. More closely monitor the winter fishing pressure and harvest for sauger and walleye;
4. Monitor the game and nongame fish for any change in growth rates since the cessation of the commercial fishery (it may be necessary to use larger mesh gill nets to optimally do this); and
5. Refine the simulation model developed by Frie to be more predictive.

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APPENDIX

Appendix Table 1. Average number and weight (lb) of fish in July assessment gill nets, Lake of the Woods, Minnesota, 1968-70[a] and 1980-84.

	1968	1969	1970	1968-70	1980	1981	1982	1983	1984	1980-84
Total lifts	40	52	40	132	45	52	51	52	52	252
Mean catch/lift										
Lake sturgeon	0.05	0.06	0.05	0.05	0.04	0.25	0.04	0.04	0.13	0.10
Mooneye	0.02			0.01			0.02		0.03	0.01
Cisco	38.75	19.38	26.68	27.46	10.08	12.67	9.53	23.21	7.42	12.66
Rainbow trout								0.02		
Northern pike	2.28	2.20	2.45	2.30	2.95	2.50	2.92	1.77	1.77	2.36
White sucker	3.82	1.97	4.98	3.44	4.11	4.59	6.22	5.44	4.37	4.96
Northern redhorse								0.02	0.13	0.03
Silver redhorse		0.02	0.15	0.05	0.13	0.11	0.08		0.23	0.11
Black bullhead									0.05	0.01
Brown bullhead								0.02		
Trout perch									0.05	0.01
Burbot		0.02	0.05	0.02	0.02			0.04		0.01
Rock bass							0.12	0.04	0.03	0.04
Smallmouth bass						0.04	0.02			0.01
Black crappie									0.01	
Yellow perch	20.60	28.56	18.40	23.07	33.46	37.13	21.75	29.85	35.10	31.44
Sauger	34.72	23.34	34.78	30.26	24.96	16.07	30.02	20.48	24.52	23.13
Walleye	7.60	9.88	10.25	9.30	9.22	7.69	9.43	4.31	9.77	8.05
Totals	107.84	85.43	97.79	95.97	84.97	81.05	80.15	85.24	83.61	82.96
Mean pounds/lift										
Lake sturgeon	0.03	0.17	0.03	0.09	0.03	0.39	0.03	0.06	0.38	0.18
Mooneye	0.02			0.01			0.02		0.01	0.01
Cisco	30.12	16.71	20.33	21.87	7.98	9.55	6.67	11.52	4.51	8.05
Rainbow trout								0.01		
Northern pike	5.03	5.39	5.72	5.38	5.89	7.01	8.39	5.15	5.81	6.46
White sucker	6.75	3.64	8.33	6.00	7.03	7.50	7.42	8.16	6.26	7.28
Northern redhorse								0.03	0.24	0.06
Silver redhorse		0.02	0.15	0.05	0.34	0.34	0.18		0.12	0.19
Black bullhead									0.01	
Brown bullhead								0.01		
Trout perch									0.00	
Burbot		0.03	0.05	0.03	0.01			0.02		0.01
Rock bass							0.04	0.01	0.01	0.01
Smallmouth bass						0.09	0.00			0.02
Black crappie									0.00	
Yellow perch	11.27	12.28	9.81	11.23	11.98	14.80	6.73	9.90	7.98	10.24
Sauger	12.44	9.77	13.70	11.77	10.81	8.43	15.55	11.84	12.79	11.90
Walleye	3.88	6.05	10.39	6.71	6.77	5.98	5.79	3.32	6.99	5.74
Totals	69.54	54.06	68.51	63.14	50.84	54.09	50.82	50.03	45.11	50.16

[a] From Schupp (1974).

Appendix Table 2. Average number and weight (lb) of fish in September assessment gill nets, Lake of the Woods, Minnesota, 1968-70[a] and 1981-84.

	1968	1969	1970	68-70	1980	1981	1982	1983	1984	82-84
Total lifts	36	43	20	99	36	48	52	52	52	240
Mean catch/lift										
Lake sturgeon		0.09		0.04	0.09	0.15		0.02	0.04	0.06
Mooneye								0.02	0.12	0.03
Tullibee	8.17	20.32	29.80	17.82	6.19	4.46	16.52	18.92	10.54	11.78
Rainbow trout										
Northern pike	1.61	2.00	1.80	1.82	4.61	2.38	1.58	1.65	1.90	2.28
White sucker	2.33	2.40	2.00	2.29	4.80	5.17	4.02	4.48	7.50	5.22
Northern redhorse					0.08			0.06	0.10	0.05
Silver redhorse					0.03	0.06	0.08			0.03
Black bullhead					0.03	0.04		0.06	0.03	0.03
Brown bullhead									0.04	0.01
Trout perch										
Burbot		0.02	0.10	0.03	0.08	0.02	0.06	0.02	0.04	0.04
Rock bass										
Smallmouth bass		0.02		0.01	0.08	0.02	0.06	0.10	0.06	0.06
Black crappie									0.15	0.03
Yellow perch	6.00	6.81	6.20	6.39	7.75	8.75	10.67	15.63	29.92	15.09
Sauger	15.61	15.09	7.10	13.66	9.94	4.54	10.10	11.60	13.79	10.09
Walleye	9.72	15.82	26.55	15.77	15.25	15.29	6.31	13.42	19.50	13.85
Totals	43.44	62.57	73.55	57.83	48.93	40.88	49.40	65.98	83.73	58.66
Mean pounds/lift										
Lake sturgeon		0.14		0.06	0.12	0.48		0.07	0.07	0.14
Mooneye								0.01	0.03	0.01
Tullibee	6.58	11.49	23.51	12.13	4.64	2.70	7.61	8.93	5.64	6.04
Rainbow trout										
Northern pike	4.87	5.69	5.29	5.31	10.88	8.15	4.16	5.48	7.12	6.89
White sucker	3.19	4.36	3.30	3.72	8.64	7.65	6.31	8.15	14.20	9.04
Northern redhorse					0.10			0.05	0.04	0.03
Silver redhorse					0.08	0.17	0.23			0.10
Black bullhead					0.01	0.04		0.03	0.04	0.02
Brown bullhead									0.02	[b]
Trout perch										
Burbot		0.03	0.10	0.03	0.33	0.08	0.08	0.05		0.09
Rock bass										
Smallmouth bass		0.02		0.01	0.12	0.02	0.12	0.12	0.02	0.08
Black crappie									0.01	[b]
Yellow perch	3.83	3.66	1.87	3.36	3.23	2.92	3.55	2.49	9.55	4.45
Sauger	7.27	6.88	3.28	6.29	6.33	2.82	6.27	5.99	10.12	6.36
Walleye	6.56	12.64	27.64	13.46	15.26	16.39	5.90	10.87	18.45	13.20
Totals	32.30	44.91	64.99	44.38	49.74	41.42	34.23	42.24	65.31	46.46

[a] From Schupp (1974).
[b] Less than 0.005.

Appendix Table 3. Estimated open-water sport fishing effort and 95% confidence intervals by catch location for Lake of the Woods, 1982-1984.

	Total boat-trips	Total man-trips	Total manhours
1982			
Minnesota	47,403	146,611	552,575
Ontario	3,944	13,940	73,570
Manitoba	1,577	6,017	34,919
Rainy River	4,259	10,910	36,469
Totals	57,183	177,478	697,533
1983			
Minnesota	35,808	109,448	421,974
Ontario	5,294	17,663	95,247
Manitoba	5,081	18,868	114,432
Rainy River	4,801	14,789	52,520
Totals	50,984	160,768	684,173
1984			
Minnesota	40,731	124,994	504,477
Ontario	5,124	17,960	90,181
Manitoba	5,208	23,007	129,957
Rainy River	4,004	13,281	39,554
Totals	55,067	179,242	764,169
Grand mean	54,411	172,496	715,292

Appendix Table 4. Estimated open-water sport fishing effort and harvest, Lake of the Woods, 15 May-18 October, 1982.

	Minnesota	Ontario	Manitoba	Rainy River	Total
Total manhours	552,575	73,570	34,919	36,469	697,533
Total catch (no)	243,479	39,140	19,697	9,945	312,261
CPUE (fish/mh)	0.44	0.53	0.56	0.27	0.45
Lake sturgeon	15	0	0	0	15
Mooneye	0	0	0	0	0
Rainbow trout	0	0	0	0	0
Northern pike	7,953	667	238	1,327	10,185
Bullhead	0	0	0	0	0
Rock bass	26	0	0	0	26
Smallmouth bass	114	90	0	25	229
Yellow perch	7,601	716	296	725	9,338
Sauger	25,615	2,559	902	1,013	30,089
Walleye	202,155	35,108	18,261	6,855	262,379
Burbot	0	0	0	0	0
Total catch (lb)	250,588	39,888	20,032	12,014	322,522
Lake sturgeon	397	0	0	0	397
Mooneye	0	0	0	0	0
Rainbow trout	0	0	0	0	0
Northern pike	23,681	1,988	710	3,949	30,328
Bullhead	0	0	0	0	0
Rock bass	20	0	0	0	20
Smallmouth bass	136	140	0	38	314
Yellow perch	4,203	396	164	401	5,164
Sauger	16,492	1,648	580	652	19,372
Walleye	205,659	35,716	18,578	6,974	266,927
Burbot	0	0	0	0	0

Appendix Table 5. Estimated open-water sport fishing effort and harvest, Lake of the Woods, 14 May-16 October, 1983.

	Minnesota	Ontario	Manitoba	Rainy River	Total
Total manhours	421,974	95,247	114,432	52,520	684,173
Total catch (no)	181,713	66,017	66,569	21,789	336,088
CPUE (fish/mh)	0.43	0.69	0.58	0.42	0.49
Lake sturgeon	12	0	0	0	12
Mooneye	30	0	0	0	30
Rainbow trout	16	0	0	0	16
Northern pike	6,984	589	896	1,495	9,964
Bullhead	27	0	0	0	27
Rock bass	31	0	0	0	31
Smallmouth bass	142	197	0	127	466
Yellow perch	5,323	3,244	1,132	614	10,313
Sauger	27,089	5,018	4,870	2,128	39,105
Walleye	142,043	56,969	56,671	17,425	276,108
Burbot	16	0	0	0	16
Total catch (lb)	196,175	71,174	67,748	27,816	362,913
Lake sturgeon	187	0	0	0	187
Mooneye	30	0	0	0	30
Rainbow trout	12	0	0	0	12
Northern pike	18,853	1,678	3,067	4,004	27,602
Bullhead	23	0	0	0	27
Rock bass	23	0	0	0	23
Smallmouth bass	214	296	0	190	700
Yellow perch	3,001	1,888	735	330	5,954
Sauger	17,334	3,348	3,271	1,425	25,378
Walleye	156,462	63,964	60,675	21,867	302,968
Burbot	32	0	0	0	32

Appendix Table 6. Estimated open-water sport fishing effort and harvest, Lake of the Woods, 12 May-20 October, 1984.

	Minnesota	Ontario	Manitoba	Rainy River	Total
Total manhours	504,477	90,181	129,957	39,554	764,169
Total catch (no)	213,528	49,988	76,137	17,789	357,442
CPUE (fish/mh)	0.42	0.55	0.59	0.45	0.47
Lake sturgeon	22	0	0	0	22
Mooneye	0	0	0	0	0
Rainbow trout	0	0	0	0	0
Northern pike	5,020	1,721	607	4,959	12,307
Bullhead	0	0	0	0	0
Rock bass	59	0	0	97	156
Smallmouth bass	205	97	0	372	674
Yellow perch	9,114	292	846	582	10,834
Sauger	24,542	1,967	1,747	114	28,370
Walleye	174,566	45,911	72,937	11,665	305,079
Burbot	0	0	0	0	0
Total catch (lb)	229,576	59,368	81,889	25,192	396,025
Lake sturgeon	457	0	0	0	457
Mooneye	0	0	0	0	0
Rainbow trout	0	0	0	0	0
Northern pike	12,110	4,526	2,173	11,319	30,128
Bullhead	0	0	0	0	0
Rock bass	44	0	0	72	116
Smallmouth bass	308	146	0	583	1,037
Yellow perch	4,593	215	729	381	5,918
Sauger	15,672	1,485	1,225	97	18,479
Walleye	196,392	52,996	77,762	12,740	339,890
Burbot	0	0	0	0	0

Appendix Table 7. Estimated average annual open-water angling effort and harvest by catch location and fishing craft for Lake of the Woods, 1968[a] and 1982-1984.

	Minnesota		Ontario		Manitoba		Rainy River		Totals	
	1968-70	1982-84	1968-70	1982-84	1968-70	1982-84	1968-70	1982-84	1968-70	1982-84
Small boat trips	32,091	21,928	719	1,206	600	388	7,535	2,277	40,945	25,799
Pleasure craft trips	b	17,852	b	2,655	b	2,509	b	1,635	b	24,651
Charter launch trips	1,585	1,534	1,165	919	336	1,058	0	443	3,086	3,954
Man-trips	112,097	127,017	8,615	16,521	4,420	15,965	19,036	12,994	144,168	172,497
Small boats	103,486	61,715	2,626	3,273	2,289	1,302	19,036	5,415	127,437	71,705
Pleasure craft		56,902		8,416		8,195		5,350		78,863
Charter launch	8,611	8,400	5,989	4,832	2,131	6,468	0	2,229	16,731	21,929
Manhours	462,217	493,008	53,644	86,333	21,243	93,102	74,322	42,848	611,426	715,291
Small boats	408,512	232,102	12,093	13,650	9,631	9,794	74,322	15,338	504,558	270,884
Pleasure		214,392		41,234		45,977		17,228		318,831
Charter launch	53,705	46,514	41,551	31,449	11,612	37,331	0	10,282	106,868	125,576
Total catch (no)	277,547	212,668	40,804	51,589	25,099	54,134	32,317	16,405	375,767	334,796
Northern pike	8,545	6,652	308	994	167	581	1,967	2,698	10,987	10,925
Small boats	7,971	4,362	43	325	82	62	1,967	1,009	10,063	5,758
Pleasure craft		1,996		354		333		1,066		3,749
Charter launch	574	294	265	315	85	186	0	623	924	1,418
Walleye	220,640	172,922	35,622	45,996	22,369	50,289	24,280	11,982	302,911	281,189
Small boats	184,470	84,866	5,928	8,258	12,305	4,448	24,280	4,950	226,983	102,522
Pleasure craft		69,286		23,866		23,809		3,920		120,881
Charter launch	36,170	18,770	29,694	13,872	10,064	22,032	0	3,112	75,928	57,786
Sauger	38,205	25,748	4,025	3,182	1,733	2,506	5,437	1,084	49,400	32,520
Small boats	36,095	11,332	1,158	516	383	185	5,437	394	43,073	12,427
Pleasure Craft		11,108		1,515		1,468		330		14,421
Charter launch	2,110	3,308	2,867	1,151	1,350	853	0	360	6,327	5,672
Yellow perch	10,157	7,346	849	1,417	830	758	633	641	12,469	10,162
Small boats	9,421	4,002	83	189	431	94	633	388	10,568	4,673
Pleasure craft		2,636		974		416		241		4,267
Charter launch	736	708	766	254	399	248	0	12	1,901	1,222
Total catch (lb)	322,703	224,817	49,671	56,616	28,350	56,556	32,983	21,380	433,707	359,369
Northern pike	27,326	18,215	826	2,731	466	1,983	3,632	6,424	32,250	29,353
Walleye	258,147	186,171	45,063	50,892	26,046	52,338	25,530	13,860	354,786	303,261
Sauger	30,077	16,499	3,187	2,160	1,377	1,692	3,426	725	38,067	21,076
Yellow perch	7,153	3,932	595	833	461	543	395	371	8,604	5,679

[a] From Schupp (1974).
[b] Included in small boat trips.

Appendix Table 8. Catch rates expressed as fish/manhour(mh) by catch location and fishing craft for Lake of the Woods walleye, 1982, 1983, and 1984.

	Minnesota no/mh	Ontario no/mh	Manitoba no/mh	Rainy River no/mh	Totals no/mh
1982					
Small boats	0.38	0.59	0.34	0.23	0.39
Pleasure craft	0.34	0.32	0.52	0.15	0.36
Chartered launch	0.39	0.36	0.56	0.13	0.39
Totals	0.37	0.48	0.52	0.19	0.38
1983					
Small boats	0.35	0.90	0.46	0.33	0.38
Pleasure craft	0.31	0.67	0.50	0.30	0.40
Chartered launch	0.40	0.42	0.60	0.3	0.45
Totals	0.34	0.69	0.52	0.33	0.40
1984					
Small boats	0.35	0.43	-.--	0.53	0.36
Pleasure craft	0.32	0.50	0.53	0.24	0.38
Chartered launch	0.42	0.55	0.59	0.19	0.50
Totals	0.35	0.51	0.56	0.30	0.40

Appendix Table 9. Estimated average annual open-water sport fishing effort and harvest by catch location, Lake of the Woods, 1982-84.

	Minnesota	Ontario	Manitoba	Rainy River	Totals
Total manhours	493,008	86,333	93,102	42,848	715,292
Total catch (no)	212,907	51,715	54,134	16,508	335,264
CPUE (fish/h)	0.43	0.60	0.58	0.39	0.47
Lake sturgeon	16	0	0	0	16
Mooneye	10	0	0	0	10
Rainbow trout	5	0	0	0	5
Northern pike	6,652	992	580	2,594	10,819
Bullhead	9	0	0	0	9
Rock bass	39	0	0	32	71
Smallmouth bass	154	128	0	175	457
Yellow perch	7,346	1,417	758	640	10,162
Sauger	25,749	3,181	2,506	1,085	32,521
Walleye	172,921	45,996	50,290	11,982	281,189
Burbot	5	0	0	0	5
Total catch (lb)	225,446	56,810	21,674	21,674	360,486
Lake sturgeon	347	0	0	0	347
Mooneye	10	0	0	0	10
Rainbow trout	4	0	0	0	4
Northern pike	18,215	2,731	1,983	6,424	29,353
Bullhead	9	0	0	0	9
Rock bass	29	0	0	24	53
Smallmouth bass	219	194	0	270	684
Yellow perch	3,932	833	543	371	5,679
Sauger	16,499	2,160	1,692	725	21,076
Walleye	186,171	50,892	52,338	13,860	303,262
Burbot	11	0	0	0	11

USERS GUIDE FOR 'WALLEYE'

Any 48K Apple II will run 'WALLEYE' upon placing the disk in Drive 1, closing the drive door, and turning the machine on. While the program is running, parameter values may be changed when the prompt CHANGE PARAMETER VALUES... THEN ENTER 'CONT' appears. For example, entering Z = .6 followed by a carriage return (pressing the RETURN key) will change the default value of Z - .76 to Z = 0.60. Several values may be changed as long as the RETURN key is pressed after each command is entered. Enter the command CONT when no more parameter changes are desired. If an error returns you to the system level with no place to proceed, enter the command RUN.

As the model continues to run past this point, values of key output variables will appear on the screen for each year of the simulation, starting with 1970 and ending with 2005. This progress can be stopped and started any number of times with the toggle CTRL-S (press the S key after holding down the CTRL key). Another option is the CTRL-C which will interrupt program control and place you at the operating system level. To examine the current value of any of the variables in the model, type PRINT nn where nn is the name of a variable in the model (Tables G1 and G2). Enter the command CONT to assume program control at the place in the program which was interrupted.

The next page contains a modified copy of page 34 from Koonce et al. (1982).

When the simulation is complete, a rectangular box will be drawn on the screen and the computer will request input from the user with the prompt:

PLOT VAR#

The user may respond with any of the following:

a) n — where n is the number from 1 to 27 corresponding to an indicator variable generated by the simulation model (see Table G1 in this report). For example, if the user types a 4 followed by a carriage return (required to terminate any input line), the computer will plot number in population which are age 5 and older at the beginning of each fishing season starting in 1970. As the results are plotted, the maximum value for the Y-axis scaling will appear on a text line at the bottom of the plotting rectangle.

b: n/30 — This response will cause indicator variable number n to be plotted on a Y-axis scale of 0 to 30 (obviously not appropriate scaling for variable 4 discussed above). This allows the user to set a particular scaling value in order to compare biomass for two or more species.

c n/1E4 P — This will plot a series of points for variable n scaled to a maximum value of ten thousand. The P parameter in this command suppresses the lines that would otherwise connect the points.

d) G — This clears the screen of any previously plotted results.

e) n ɃCI — Plots variable n in any of the Apple colors numbered from 1 to 6. The "Ƀ" represents a blank, the "C" character is required and the "I" is a numeric character from 1 to 6. Note that a command of 9 Ƀ C 4 will appear to erase variable 9 from the screen if this variable has previously been plotted in a color other than 4. This is because color 4 is BLACK.

f) S filename — Will cause the computer to store the current image of the graphics screen in a file by the name specified in the "filename" argument. This file will be written onto the disk currently residing in the disk drive.

g) R filename — This will ERASE THE CURRENT SCREEN IMAGE and replace it with an image previously stored by an S filename command.

The following two commands are the result of coding modifications to MICRO SIMCON.

h) Q — Quit the program, erase the graphics screen, and return control to the operating system. You may now make whatever changes you wish in the basic structure of the simulation model. Any changes made to the program can be saved to disk with the command SAVE nn, where nn is the name of the version of WALLEYE you choose. However, the 'WALLEYE' in line 1 must be changed to nn before issuing the SAVE command (Table G4).

i) D — This causes the program to jump to the subroutine below. The subroutine creates a text file on disk containing some of the plotting variables. Designated variables by number (Table G1) are in the DATA statement of line 13010.

```
13000   PRINT "DUMP OUTPUT TO TEXT FILE": INPUT "NAME OF TEXT FILE?
        ":D$: INPUT "DUMP HOW MANY VARIABLES? ";DN: IF DN < 1 or DN >
        NV THEN 13000
13010   DATA  6,9,14,15,17,18,27: FOR I = 1 TO DN: READ V(I): NEXT
13020   PRINT  CHR$ (4);"OPEN ";D$: PRINT  CHR$ (4);"DELETE ";D$
        :PRINT  CHR$ (4);"OPEN ";D$: PRINT  CHR$ (4);"WRITE ";D$
13030   PRINT ZS: PRINT NT: PRINT DN
13040   FOR I = 1 TO DN: PRINT ZM(V(I))
13050   FOR J = ZS TO NT: PRINT Z(V(I),J): NEXT : NEXT
13060   PRINT  CHR$ (4);"CLOSE ";D$: RETURN
```

The text file is read by a modified version of another plotting program, MULTI SIMCON, for contrasting the outcomes of several different scenarios. MULTI SIMCON was developed by C.K. Minns, Great Lakes Biolimnology Lab, Canada Center for Inland Waters, P.O. Box 5050, Burlington, Ontario, Canada L7R 4A6, (416) 637-4730.

Using Figure 22 as an example, the command was issued each time after making the appropriate changes to line 100 (Table G4). Six text files were created on disk as a result. Then, upon exiting the WALLEYE program, the following procedure was followed (User's responses are underlined):

1) RUN MULTISIMCON
2) ENTER COMMANDS, THEN CONT
3) CONT
4) SIM FROM -- GR This response opens the graphics window on the screen.
5) PLOT VAR NO. -- DL
6) ENTER FILE NAME -- MINSIZE13 This specified the filename containing the previously saved results of the simulation where a minimum size limit of 13 inches was used. Indicator variables are loaded into variable locations starting with 1.

Repeat steps 5 and 6, specifying a different filename until all scenarios are loaded.

List of Plotting Variables

Plotting variables are of the form, Z(n,TI), where n is the number of the variable in this list and TI is the time step of the simulation. The term "actual" implies that intuition was used to fill gaps in the time series.

1. Coefficient of variation of mean daily air temperature during May 15-July 15 of each year 1951-1978 at International Falls, Minnesota.
2. Total abundance (ages 1-16) at beginning of fishing season.
3. Abundance of young of the year at beginning of fishing season.
4. Number in population which are age 5 or older at beginning of fishing season.
5. Sport and commercial catch combined (numbers).
6. Sport and commercial catch combined which is killed (number creeled and gilled).
7. Sport and commercial catch combined which is killed (pounds).
8. Sport catch (numbers).
9. Number creeled.
10. "Actual" number creeled.
11. Weight creeled (pounds).
12. "Actual" weight creeled (pounds).
13. Angler-hours.
14. Sport catch (numbers) per angler-hour.
15. Number creeled per angler-hour.
16. "Actual" number creeled per angler-hour.
17. Weighted mean length of walleye in the sport catch.
18. Weighted mean length of walleye in sport creel.
19. Commercial gill net catch (numbers).
20. Actual commercial gill net catch (numbers).
21. Commercial gill net catch (pounds).
22. Actual commercial gill net catch (pounds).
23. Actual commercial gill net effort (1000s of feet of net).
24. Commercial catch per unit of effort (pounds per 1000 feet of net).
25. Actual commercial catch per unit of effort (pounds per 1000 feet of net).
26. Biomass (in pounds) of age 5 and older walleye in the population.
27. Tic marks for years.

List of Variables Used in the Simulation Program

A	- Total annual mortality rate for ages 3-10.
A1	- Total number of female spawners for the next year.
A2	- Proportion of A1 in which the Ricker recruitment function would then be used.
A3	- Increase in A1 in which the Ricker recruitment function would then be used.
A5	- Total number of male and female spawners. This constant is used only to start the simulation and serve as criterion for use of the Ricker recruitment function.
A6	- number of fry naturally produced.
A7	- Parameter of Ricker recruitment curve.
A8	- Parameter of Ricker recruitment curve.
A9	- Number of fry stocked.
AB	- Parameter for weight-length relationship for walleye over 22 inches long.
AD	- Standard deviation (expressed as percentage of the mean) of the number of age-0 fish produced by the Ricker recruitment curve.
AV(i)	- Average abundance of age i during the fishing season.
AW	- Parameter for weight-length relationship for walleye less than 23 inches long.
BB	- Parameter for weight-length relationship for walleye over 22 inches long.
BL	- Maximum size limit (inches).
BW	- Parameter for weight-length relationship for walleye less than 23 inches long.
CO-C2	- Parameters for curves relating commercial exploitation rates to fish length (9inches).
C3-C4	- Chance that angler will cull a fish of age 3 (C3) or 4 (C4) from the creel stringer.
C5(i)	- Number creeled in age class i.
CE	- Commercial fishing effort flag (0 = no fishing after 1984, i = constant effort at the 1984 amount).
CR(i)	- Probability that a fish of age i will be creeled once it is caught.

CS - Total number creeled.

CV - Average annual coefficient of variation of mean daily air temperature during May 15-July 15 during 1951-1978 at International Falls, MN.

EA - Number of angler-hours in 1982, used to determine catchability from tagging study.

EC - Commercial effort in 1982, used to determine catchabilities from tagging study.

ED - Total number of eggs deposited during spawning.

EGGS - Number of eggs per pound of female spawner.

ES - Survival rate from egg to hatching.

FC(i) - Instantaneous commercial fishing mortality rate for age i.

FI - Maximum age in model.

FS(i) - Instantaneous angling mortality rate for age i.

H(i) - Annual hooking mortality rate for age i.

K1, K2 - Minimum and maximum size classes (9inches) of a given age.

KI - K-parameter for von Bertalanffy growth curve.

KEY(i,k) - Probability that a fish in length class k and is age i.

L(i) - Mean length at age i.

L5(i) - Number caught of age i by commercial fishermen.

L7(i) - Number caught of age i by anglers.

LC - Total number caught by commercial fishermen.

LI - L-infinity length parameter in von Bertalanffy growth function.

LS - Total number caught by anglers.

M(i) - Instantaneous natural mortality rate for age i.

ME - Maximum angling effort (angler-hours).

MH - Weighted mean length in sport catch.

MK - Weighted mean length in creel.

NO(i) - Abundance of age i at beginning of fishing season.

N1(i) - Abundance of age i at end of fishing season.

NE - Proportion of angling effort reduced due to season closures.

NT - Number of years for simulation to run.

NV - Number of plotting variables.

P - Variable which stores relative abundance of age i at beginning of simulation.

PF - Proportion of spawners which are female.

QC(i),QS(i) - Age specific Type 2 catchabilities for commercial and sport fisheries, respectively.

RC - Reporting rate on commercial tags.

RS - Reporting on sport tags.

SO-S2 - Parameters for curves relating sport exploitation rates to fish length (inches).

SA - Minimum age of vulnerability to sport fishery

SE - Sport fishing effort flag (0 = constant effort after 1984, 1 = linearly increasing).

SI(i) - Proportional multiplier for sport exploitation rate after commercial fishing is stopped.

SL - Minimum size limit (inches).

TO - Time-0 parameter for von Bertalanffy growth curve.

TI - Time step number in the simulation.

TK(i),TL(i) - Mean length at age i times number caught and also times number creeled at age i, respectively. Used as intermediate step for computing weighted mean length in the catch and creel.

TV - Standard deviation expressed as percentage of the mean coefficient of variation of daily air temperatures, May 15-June 15, 1951-1978 at International Falls, MN.

UC(i) - Annual commercial exploitation rate for age i.

US(i) - Annual sport exploitation rate for age i.

V(j) - Array which stores certain plotting variable numbers j for dumping to a text file on disk.

W(i) - Average weight (pounds) for a fish of age i.

W5(i) - Weight (pounds) creeled for age i.

WC - Weight (pounds) creeled.

WK - Total yield (pounds) to both fisheries.

WT - Average weight (pounds) of a fish in the commercial gill net catch.

X1 - Choice (X1 = 0, 1, 2, 3, 4) for type of size regulation:
0 = no size restriction
1 = maximum size limit (--BL)
2 = minimum size limit (SL--)
3 = protected slot limit (--SL, BL--)
4 = catch window limit (SL-- , --BL).

X2 - Choice (X2 = 0, 1, 2, 3, 4) for type of reproduction function:

0 = constant recruitment

1 = egg deposition and mortality schedule

2 = Ricker stock-size/recruitment function

3 = Random number of fry produced according to variation in temperature between May 15 and June 15

4 = Combination of 2 and 3, where Ricker function is used at low and high levels of female spawner abundance.

YI - Number of female spawners.

YE - Number of yearlings stocked.

YR - Year that simulation begins.

Z - Total instantaneous mortality rate for ages 3-10.

Z(j) - Plotting variable number j.

ZR - Random number from standard normal distribution.

ZS - Starting time-step in simulation.

Line Numbers where Variables and Parameters Appear in the Simulation Program

The model user can change parameter values at the first line number referenced

A:	140 510
	10140 10150 10160 10180 10200
	10240 10260 10280 10360 10380
	10420 10440 10460 10480 10560
	10600 10610 10620 10630 10635
	10640 10680 10700 10720 10740
	10760 10770 11060
A1	390 1210 1410 2220
A2:	380 1410
A3:	380 1410
A5:	350 390 1410
A6:	120 430 1120 1210 1320 2040 2240
A7:	260 1210
A8:	260 1210
A9:	190 2040
A8:	280 470
AD:	260 1210
AV(:	40 2150 2160 2180
AW:	280 460
BB:	280 470
BL:	100 1510 1710 1810
BW:	280 460
CO:	290 490
CI:	290 490
C2:	290 490
C3:	320 330 2070
C4:	320 330 2070
C5(:	40 2180 2190 2290
CE:	110 640
CR(:	40 330 1510 1610 1710 1810 2070
	2140 2180
CS:	2190 2200 2280 2300 2310
CV:	250 1310
D$:	13000 13020 13060
DN:	13000 13030 13040
DP:	3
EA:	410 510
EC:	410 510
ED:	1110 1120
EG:	370 1110
ES:	340 1120
FC(:	40 2110 2130 2140 2160
FF:	9010 9020
FS(:	40 2120 2130 2140 2160 2180
H(:	40 210 2140
K1:	560 570 580 590 1000
K2:	560 570 580 590 1000
KE(:	40 1000 1510 1610 1710 1810
KI:	270 450
L(:	40 450 460 470 490 500 2290

L5(:	40 2160 2170
L7(:	40 2160 2170 2180 2290
LC:	2170 2200 2310
LI:	270 450
LS:	2170 2270 2300 2310
M(:	40 180 2100 2140
MA:	9010 9030 9040
ME:	230 690
MH:	2300 2310
MK:	2300 2310
NO(:	40 2060 2100 2140 2150 2250 2260 2310
N1(:	40 430 440 1110 2040 2050 2060 2100 2140 2150 2210 2220
NE:	220 710
NT:	5 30 640 690 2000 10820 10920 10980 11320 11380 13030 13050
NV:	20 40 9000 9040 10000 13000
P:	430 440
PF:	360 390 1110 1410 2220
QC(:	40 510 2110
QS(:	40 510 520 2120
RC:	130 490
RE$:	1120 1210 1320 2240 2350
RS:	130 500
S0:	300 500
S1:	300 500
S2	300 500
SA:	20 330 450 490 510 1510 1610 1710 1810 2100 2110 2120 2130 2140 2160 2170 2180 2190 2290 2300
SE:	110 690 700
SI(:	40 2130
SL:	100 1610 1710 1810
TO:	270 450
TI:	1310 1320 2000 2070 2110 2120 2130 2170 2200 2250 2260 2270 2280 2310 2330 2340 2350 9000 9040 10020 10040 10090
TK(:	40 2290 2300
TL(:	40 2290 2300
TT:	30 40
TV:	250 1310
UC(:	40 490 510
US(:	40 500 510
V(:	40 13040 13050
W:	3
W(:	40 460 470 1110 2180
W5(:	40 2180 2190
WC:	2190 2200 2310
WT:	240 660 2200 2310
X1:	100 2070
X2:	100 2230
XT:	10540 11160

YE:	200 2050
YR:	20 2010 2020 9020
Z:	140 510
Z(:	40 610 630 640 660 670 680 690
	700 710 720 730 1310 1320 2110
	2120 2170 2200 2250 2260 2270
	2280 2310 2330 2340 2350 9000
	9040 10020 10040 10860 10940
	11020 11260 11340 11400 13050
Z1:	10820 10940 11020 11060 11140
	11160 11260 11340 11400
Z2:	10820 10840 10860 10940 11020
	11060 11200 11220 11260 11340
	11400
Z3:	10480 10520 10540
Z4:	10520 10840 11220
Z5:	10320 10540 11160
Z6:	10320 10500 10520 10840 11220
Z7:	11260 11320 11380
Z8:	10860 10920 10940 10980 11000
	11020 11320 11340 11380 11400
ZC:	10620 10790 11250
ZM(:	40 10020 10800 10820 10840 11140
	11160 11200 11220 13040
ZP:	10640 10660 10900 11300
ZR:	1210 1310 12000
ZS:	20 2000 9000 10820 10860 10920
	11000 11260 13030 13050

BASIC Program Listing, called 'WALLEYE', for the Simulation Model of the Walleye Population and Fishery of Lake of the Woods

```
--------------------
1      IF PEEK (104) < > 64 THEN POKE 104,64
    * : POKE 103,1
    * : POKE 16384,0
    * : PRINT CHR$ (4);"RUN WALLEYE"
    * : REM   PROTECT GRAPHICS MEMORY AREA
--------------------
2        CLEAR
       : TEXT
       : HOME
       : PRINT "WALLEYE MODEL FOR LAKE OF THE WOODS"
       : PRINT
       : PRINT "  RICHARD FRIE,","SEPTEMBER 1985"
       : VTAB 5
--------------------
3        DP = 100
       : DEF FN RD(W) = INT (W * DP + .5) / DP
       : REM  ROUNDING FUNCTION
--------------------
5        PRINT
       : INPUT "SIMULATE HOW MANY YEARS? ( >15) ";NT
       : NT = INT (NT)
       : IF NT  <0 OR NT  >80 THEN 5
--------------------
10        PRINT
       :  PRINT "SETTING INITIAL VALUES, WAIT"
--------------------
20       ZS - 1
       : FI = 16
       : NV = 27
       : YR -1970
       : SA = 3
       : REM  AGE RANGE, START YEAR, NUMBER OF PLOTTING VARS
--------------------
30       TT = NT
       : IF NT  < 15 THEN TT = 15
--------------------
40       DIM H(FI),M(FI),N1(FI),TL(FI),CR(FI),NO(FI),AV(FI),Z(NV,TT),ZM
            (NV),L(FI),UC(FI),US(FI),QC(FI),QS(FI),L7(FI),L5(FI),C5(FI
            ),W(FI),KEY(FI,28),SI(FI),W5(FI),FC(FI),FS(FI),TK(FI),V(NV
            )
--------------------
100      X1 = 0
       : BL = 18
       : SL = 13
       : X2 = 0
       : REM  SIZE LIMITS AND RECRUITMENT
--------------------
110      CE = 0
       : SE = 1
       : REM     COMMERCIAL AND SPORT EFFORT FLAGS
--------------------
```

```
--------------------
120     A6 = 200E6
      : REM  NUMBER OF FRY
--------------------
130     RC = .9
      : RS = .5
      : REM  COMMERCIAL AND SPORT TAG REPORTING
--------------------
140     Z = .76
      : A = .53
      : REM  INST AND ANNUAL TOTAL MORTALITY
--------------------
180     M(0) = 3
      : M(1) = 1.4
      : M(2) = .92
      : FOR I = 3 TO FI
      :   M(I) = .22
      : NEXT
      : REM  INST NATURAL MORT (AGE 0 A = 95%, AGE 1 A = 75%, AGE 2 A = 60%,
             AGES 3-16 V = M*A/Z = 15.4%
--------------------
190     A9 = 0
      : REM  NUMBER OF FRY STOCKED
--------------------
200     YE = 0
      : REM  NUMBER OF FINGERLINGS STOCKED
--------------------
210     H(3) = .29
      : H(4) = .29
      : FOR I = 5 TO FI
      :   H(I) = .1
      : NEXT
      : REM  INST HOOKING MORTALITY (AGES 3 AND 4 = 25%, AGES 5-12 = 10%)
--------------------
220     NE = 0
      : REM  SEASON CLOSURES
--------------------
230     ME = 3E6
      : REM  MAXIMUM ANGLER HOURS AFTER 1984
--------------------
240     WT = 2
      : REM  AVERAGE WT OF FISH IN COMMERCIAL CATCH
--------------------
250     CV = 13.6
      : TV = .23
      : REM    AVG COEF OF VAR OF AIR TEMP WITH STAND DEV
--------------------
260     A7 = 45.3
      : A8 = - .105
      : AD = .6
      : REM  RICKER RECRUITMENT CURVE PARMS
--------------------
```

```
--------------------
270     LI = 29.6
      : KI = .132
      : TO = - .412
      : REM  VON B GROWTH PARMS
--------------------
280     AW = 2.131E - 4
      : BW = 3.15
      : AB = 3.152E - 4
      : BB = 3.055
      : REM  WT-LENGTH RELATION PARMS
--------------------
290     C0 = - .54334
      : C1 = .064157
      : C2 = - .0016168
      : REM  PARMS FOR QUADRATIC CURVES RELATING LENGTH TO COMMERCIAL
             EXPLOIT. RATES
--------------------
300     S0 = - .02539
      : S1 = .020658
      : S2 = - .0006926
      : REM  PARMS FOR QUADRATIC CURVES RELATING LENGTH TO SPORT EXPLOIT.
             RATES
--------------------
310     DATA     0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
      : FOR I = 1 to FI
      :   READ SI(I)
      : NEXT
      : REM  PROPORTIONAL INCREASE IN SPORT CATCHABILITY AFTER COMMERCIAL
             FISHING STOPPED
--------------------
320     C3 = .3
      : C4 = .5
      : REM   CHANCE THAT ANGLER WILL RELEASE OR CULL AGE 3 (C3) AND
              AGE 4 (C4) FROM STRINGER
--------------------
330     FOR I = SA TO FI
      :   CR(I) = 1
      : NEXT
      : CR(3) = CR(3) * C3
      : CR(4) = CR(4) * C4
      : REM   PROB OF CREELING ONCE CAUGHT
--------------------
340     ES = 5.544E - 3
      : REM  ANNUAL SURVIVAL RATE FROM EGG TO HATCHING
--------------------
350     A5 = 1E6
      : REM  ABUNDANCE OF SPAWNERS
--------------------
360     PF = .75
      : REM  PROPORTION OF SPAWNERS WHICH ARE FEMALE
--------------------
```

```
--------------------
370     EGGS = 23000
      : REM  NUMBER OF EGGS PRODUCED PER POUND OF FEMALE
--------------------
380     A2 = .10
      : A3 = 2
      : REM  LOWER AND UPPER BOUNDS FOR PERCENT OF FEMALE SPAWNERS TO BEGIN
             RICKER RECRUITMENT
--------------------
390     A1 = A5 * PF
      : REM  INITIAL ABUNDANCE OF SPAWNING FEMALES
--------------------
410     EC = 4173
      : EA = 807620
      : REM  COMMERCIAL EFFORT (1000S FT NET) AND ANGLER HOURS FOR 1982
--------------------
420     DATA                 .05,.25,.4,.5,.5,.5,.5,.5,.5,.5,.5,.5,.5,1,1,1
      : REM  ANNUAL SURVIVAL RATES FOR AGES 0-16
--------------------
430     READ P
      : N1(1) = P * A6
--------------------
440     FOR I = 2 TO FI
      :   READ P
      :   N1(I) = P * N1(I - 1)
      : NEXT I
      : REM  NUMBERS BY AGE AT START USING SURVIVAL RATES FROM 420
--------------------
450     FOR I = SA TO FI
      :   L(I) = LI * (1 - EXP ( - KI * (I - TO)))
      : REM  USE VON B FUNCTION TO FIND MEAN LENGTH AT AGE
--------------------
460     IF I < = 8 THEN W(I) = AW * (L(I) © BW
   *  : REM   CONVERT AVG LENGTH TO AVG WT
--------------------
470     IF I > = 9 THEN W(I) = AB * (L(I) © BB)
--------------------
480     NEXT
--------------------
490     FOR I = SA TO 12
      :   UC(I) = CO / RC + (C1 / RC) * L(I) + (C2 / RC) * (L(I) © 2)
      :   IF UC(I) < 0 THEN UC(I) = 0
   *  :   REM    AGE SPECIFIC ANNUAL COMMERCIAL EXPLOITATION RATES
--------------------
500       US(I) = S0 / RS + (S1 / RS) * L(I) + (S2 / RS) * (L(I) © 2)
      : NEXT
      : REM   AGE SPECIFIC ANNUAL SPORT EXPLOITATION RATES
--------------------
510     FOR I = SA TO 12
      :   QC(I) = (UC(I) * Z) / (A * EC)
      :   QS(I) = (US(I) * Z) / (A * EA)
      : NEXT
      : REM   AGE SPECIFIC TYPE 2 CATCHABILITY
--------------------
```

```
--------------------
520      FOR I = 13 TO FI
       :   QS(I) = QS(12) * .5
       : NEXT
       : REM   CATCHABILITIES OF LUNKERS ARE HALF OF AGE 12
--------------------
525      REM  BELOW IS AGE-LENGTH KEY DATA
--------------------
530      DATA     7.6,54.3,38,7.5,39.6,41.5,11.3,8.4,25.2,41.1,25.2
--------------------
540      DATA        7.1,35.7,45.2,11.9,2.2,18.5,40.2,29.3,9.8,1.1,7.7,
            22,31.9,24.2,13.2,2.1,6.3,33.3,31.3,22.9,4.2,3.7,9.3,13,24.1,
            16.7,25.9,7.4,23.1,38.5,23.1,15.4
--------------------
550      DATA    25,25,25,25,15,55,15,15,17,33,17,33,40,20,20,20,100,50,50,100
--------------------
560      I = 1
       : K1 = 6
       : K2 = 8
       : GOSUB 1000
       : I = 2
       : K1 = 8
       : K2 = 11
       : GOSUB  1000
       : I = 3
       : K1 = 10
       : K2 = 13
       : GOSUB  1000
--------------------
570      I = 4
       : K1 = 12
       : K2 = 15
       : GOSUB 1000
       : I = 5
       : K1 = 13
       : K2 = 17
       : GOSUB 1000
       : I = 6
       : K1 = 14
       : K2 = 19
       : GOSUB 1000
       : I = 7
       : K1 = 15
       : K2 = 20
       : GOSUB 1000
--------------------
```

```
--------------------
580     I = 8
      : K1 = 16
      : K2 = 22
      : GOSUB 1000
      : I = 9
      : K1 = 19
      : K2 = 22
      : GOSUB 1000
      : I = 10
      : K1 = 21
      : K2 = 24
      : GOSUB 1000
      : I = 11
      : K1 = 24
      : K2 = 27
      : GOSUB 1000
      : I = 12
      : K1 = 24
      : K2 = 27
      : GOSUB 1000
--------------------
590     I = 13
      : K1 = 24
      : K2 = 27
      : GOSUB 1000
      : I = 14
      : K1 = 26
      : K2 = 26
      : GOSUB 1000
      : I = 15
      : K1 = 27
      : K2 = 28
      : GOSUB 1000
      : I = 16
      : K1 = 28
      : K2 = 28
      : GOSUB 1000
--------------------
595     REM  END AGE-LENGTH KEY DATA
--------------------
600     DATA    18.3,15.6,11.5,11.6,12.6,10.6,12.3,9.1,13.2,15.2,11.3,8.7,
                9.5,15,12.4
--------------------
610     FOR I = 1 TO 15
      :   READ Z(1,I)
      : NEXT
      : REM  HISTORICAL VARIATIONS IN SPRING TEMPS
--------------------
620     DATA   4699,5130,5648,5551,4764,4146,4026,3753,4073,4334,3996,4374,
               4173,4094,3300
--------------------
```

```
--------------------
630     FOR I = 1 to 15
      :   READ Z(23,I)
      : NEXT
      : REM   ACTUAL COMM. FISHING EFFORT
--------------------
640     IF NT > 15 THEN IF CE THEN FOR I = 16 TO NT
   *  :   Z(23,I) = Z(23,15)
   *  : NEXT
   *  : REM     CONSTANT COMMERCIAL EFFORT AT THE 1984 AMOUNT
--------------------
650     DATA    83958,112648,258631,281672,205809,153116,136924,179958,
                158752,126080,124548,233016,133286,172238,160261
--------------------
660     FOR I = 1 to 15
      :    READ Z(22,I)
      :    Z(20,I) = Z(22,I) / WT
      : NEXT
      : REM  ACTUAL COMM. GILL NET CATCH IN LBS AND NUMBERS
--------------------
670     FOR I = 1 TO 15
      :   Z(25,I) = Z(22,I) / Z(23,I)
      : NEXT
      : REM  ACTUAL COMM. CPUE
--------------------
680     J = 21
      : FOR I = 1 TO 15
      :   J = J + 1
      :   Z(13,I) = 11788 * J + 406831
      : NEXT
      : REM  ANGLER-HOURS
--------------------
690     FOR I = 16 to NT
      :   IF SE THEN J = J + 1
   *  :   Z(13,I) = 11788 * J + 406831
   *  :   IF Z(13,I) > ME THEN Z(13,I) = ME
   *  :   REM         LINEARLY INCREASING SPORT EFFORT
--------------------
700       IF NOT SE THEN Z(13,I) = Z(13,15)
   *  :   REM      CONSTANT SPORT EFFORT AT THE 1984 AMOUNT
--------------------
710       Z(13,I) = Z(13,I) - (Z(13,I) * NE)
      : NEXT
      : REM   REDUCE SPORT EFFORT BY SEASON CLOSURE
--------------------
720     FOR I = 1 TO 15
      :   Z(16,I) = - 6.526E - 7 * Z(13,I) + .95
      : NEXT
      : REM 'ACTUAL' NUMBER CREELED PER ANGLER-HOUR
--------------------
```

```
--------------------
730     FOR I = 1 TO 15
      :   Z(10,I) = Z(16,I) * Z(13,I)
      :   Z(12,I) = Z(10,I) * 1.1
      : NEXT
      : REM  'ACTUAL' NUMBER AND WEIGHT CREELED
--------------------
997     PRINT
      : PRINT "CHANGE PARAMETER VALUES IF DESIRES,"
      : PRINT "THEN ENTER 'CONT'"
      : END
--------------------
998     REM    END INITIAL CONDITIONS--START SUBROUTINES
--------------------
999     GOTO 2000
--------------------
1000    FOR K = K1 to K2
      :   READ KEY(I,K)
      :   NEXT
      : RETURN
      : REM  LOAD AGE-LENGTH KEY ARRAY
--------------------
1100    REM   RECRUITMENT FROM EGG DEPOSITION
--------------------
1110    ED = 0
      : ED = ED + W(5) * .5 * EGGS * N1(5) * .333
      : FOR I = 6 TO FI
      :   ED = ED + W(I) * EGGS * N1(I) * PF
      : NEXT
--------------------
1120    A6 = ED * ES
      : RE$ = "EGG DEPOSITION"
--------------------
1130    RETURN
--------------------
1200    REM   RECRUITMENT BASED ON RICKER CURVE
--------------------
1210    A6 = A7 * (A1 / 25E4) * EXP (A8 * (A1 / 25E4) + AD * ZR)
      : A6 = A6 * 25E5
      : RE$ = "RICKER"
--------------------
1220    RETURN
--------------------
1300    REM   RANDOM RECRUITMENT BASED ON SPRING TEMP VARIATION
--------------------
1310    IF TI  > 15 THEN GOSUB 12000
   *  : Z(1,TI) = ZR * TV + CV
--------------------
1320    A6 = 2.75E8 - (1.24E7 * Z(1,TI))
      : RE$ = "TEMPERATURE"
--------------------
1330    RETURN
--------------------
```

```
--------------------
1400    REM   COMBINATION RICKER AND TEMPERATURE RECRUITMENT FUNCTIONS
--------------------
1410    IF A1  > A2 * A5 * PF AND A1  < A3 * A5 * PF THEN 1310
--------------------
1420    GOTO 1200
--------------------
1500    REM   MAXIMUM SIZE LIMITS
--------------------
1510    FOR I = SA TO FI
      :   FOR K = 6 TO INT (BL - .5)
      :     CR(I) = CR(I) + KEY(I,K)
      :   NEXT
      :   CR(I) = CR(I) / 100
      : NEXT
--------------------
1520  : RETURN
--------------------
1600    REM   MINIMUM SIZE LIMITS
--------------------
1610    FOR I = SA TO FI
      :   FOR K = INT (SL) TO 28
      :     CR(I) - CR(I) + KEY(I,K)
      :   NEXT
      :   CR(I) = CR(I) / 100
      : NEXT
--------------------
1620    RETURN
--------------------
1700    REM   SLOT SIZE LIMITS
--------------------
1710    FOR I = SA TO FI
      :   FOR K = 6 TO INT (SL - .5)
      :    CR(I) = CR(I) + KEY(I,K)
      :   NEXT
      :   FOR K = INT (BL) TO 28
      :     CR(I) = CR(I) + KEY(I,K)
      :   NEXT
      :   CR(I) = CR(I) / 100
      : NEXT
--------------------
1720    RETURN
--------------------
1800    REM   WINDOW SIZE LIMITS
--------------------
1810    FOR I = SA TO FI
      :   FOR K = INT (SL) TO INT (BL - .5)
      :     CR(I) = CR(I) + KEY(I,K)
      :   NEXT
      :   CR(I) = CR(I) / 100
      : NEXT
--------------------
1820    RETURN
--------------------
```

```
--------------------
1999    REM  END SUBROUTINES--BEGIN SIMULATION
--------------------
2000    FOR TIME = ZS TO NT
--------------------
2010      PRINT
      :   PRINT "SIMULATION YEAR = ";YR
--------------------
2020      YR = YR + 1
--------------------
2040      N1(0) = A6 + A9
      :   REM  ADD STOCKED FRY
--------------------
2050      N1(1) = N1(1) + YE
      :   REM  ADD STOCKED FINGERLINGS
--------------------
2060      FOR I = 0 TO FI
      :     NO(I) = N1(I)
      :   NEXT
      :   REM  STORE NUMBERS AT BEGINNING OF YEAR
--------------------
2070      IF TI = 16 THEN IF X1  THEN FOR I = 1 TO FI
    * :    CR(I) = 0
    * :   NEXT
    * :   ON X1 GOSUB 1500,1600,1700,1800
    * :   CR(3) = CR(3) * C3
    * :   CR(4) = CR(4) * C4
    * :   REM  APPLY LENGTH REGULATIONS
--------------------
2100      FOR I = 0 TO SA - 1
      :     N1(I) = NO(I) * EXP ( - M(I))
      :   NEXT
      :   REM  APPLY MORTALITY TO PRE-RECRUITS
--------------------
2110      FOR I = SA TO FI
      :     FC(I) = QC(I) * Z(23,TI)
      :   NEXT
      :   REM  CALCULATE INST COMM. FISHING MORT
--------------------
2120      IF TI = 1 THEN FOR I = SA TO FI
    * :     FS(I) = QS(I) * Z(13,TI)
    * :   NEXT
    * :   REM   INST ANGLING MORT IS CONSTANT IN SPITE OF INCREASING PRESSURE
--------------------
2130      IF TI = 16 THEN FOR I = SA TO FI
    * :     FS(I) = FS(I) + SI(I) * FC(I)
    * :   NEXT
    * :   REM  INCREASE SPORT MORTALITY WITH INCREASE IN ANGLING TECHNOLOGY
--------------------
```

```
--------------------
2140      FOR I = SA TO FI
        :   N1(I) = NO(I) * EXP ( - (M(I) + FC(I) + FS(I) * CR(I) + FS(I) *
            (1 - CR(I)) * H(I)))
        :   NEXT
        :   REM   ABUNDANCE OF EACH AGE CLASS AT END OF YEAR
--------------------
2150      FOR I - 0 TO FI
        :   AV(I) = (N1(I) + NO(I)) / 2
        :   NEXT
        :   REM  AVERAGE ABUNDANCE
--------------------
2160      FOR I = SA TO FI
        :   L5(I) = FC(I) * AV(I)
        :   L7(I) = FS(I) * AV(I)
        :   NEXT
        :   REM  CATCH BY AGE FOR COMMERCIAL AND SPORT
--------------------
2170      LC = 0
        :   LS = 0
        :   FOR I = SA TO FI
        :     LC = LC + L5(I)
        :     LS = LS + L7(I)
        :   NEXT
        :   Z(5,TI) = LC + LS
        :   REM   TOTAL CATCH BY COMMERCIAL AND SPORT
--------------------
2180      PRINT "AGE","CAUGHT","KEPT"
        :   FOR I = SA TO FI
        :     C5(I) = FS(I) * CR(I) * AV(I)
        :     W5(I) = W(I) * C5(I)
        :     PRINT I, INT (L7(I)), INT (C5(I))
        :   NEXT
        :   REM   NUMBER AND WT CREELED IN EACH AGE CLASS
--------------------
2190      CS = 0
        :   WC = 0
        :   FOR I = SA TO FI
        :     CS = CS + C5(I)
        :     WC = WC + W5(I)
        :   NEXT
        :   REM   TOTAL NUMBER AND WT CREELED
--------------------
2200      Z(6,TI) = CS + LC
        :   Z(7,TI) = WC + LC * WT
        :   REM   TOTAL NUMBER AND WT KILLED BY BOTH FISHERIES
--------------------
2210      FOR I = FI TO 1 STEP - 1
        :     N1(I) = N1(I - 1)
        :   NEXT
        :   REM  AGE FISH BY 1 YR
--------------------
```

```
--------------------
2220      A1 - 0
      :   FOR I = 5 TO FI
      :     A1 = N1(I) * PF + A1
      :   NEXT
      :   REM   NUMBER OF FEMALE SPAWNERS FOR NEXT YEAR
--------------------
2230      IF X2 THEN ON X2 GOSUB 1100,1200,1300,1400
   *  :   GOTO 2250
   *  :   REM   APPLY RECRUITMENT SCENARIO
--------------------
2240      RE$ = "CONSTANT"
      :   A6 = 200E6
      :   REM   CONSTANT RECRUITMENT SCENARIO
--------------------
2250      Z(2,TI) = 0
      :   FOR I = 1 TO FI
      :     Z(2,TI) = Z(2,TI) + NO(I)
      :   NEXT
      :   REM   TOTAL ABUNDANCE AT BEGINNING OF FISHING SEASON
--------------------
2260      Z(4,TI) = 0
      :   Z(26,TI) = 0
      :   FOR I = 5 TO FI
      :     Z(4,TI) = Z(4,TI) + NO(I)
      :     Z(26,TI) = NO(I) * W(I) + Z(26,TI)
      :   NEXT
      :   REM   NUMBER AND BIOMASS OF AGE 5 OR OLDER AT BEGINNING OF FISHING
                SEASON
--------------------
2270      Z(14,TI) = LS / (Z(13,TI) + 1)
      :   REM   SPORT CATCH (NUMBERS) PER ANGLER-HOUR
--------------------
2280      Z(15,TI) = CS / (Z(13,TI) + 1)
      :   REM   NUMBER CREELED PER ANGLER-HOUR
--------------------
2290      FOR I = SA TO FI
      :     TL(I) = L(I) * L7(I)
      :     TK(I) = L(I) * C5(I)
      :   NEXT
      :   REM  COMPUTE WEIGHTED MEAN LENGTH
--------------------
2300      MH = 0
      :   MK = 0
      :   FOR I = SA TO FI
      :     MH = MH + TL(I)
      :     MK = MK + TK(I)
      :   NEXT
      :   MH = MH / (LS + 1)
      :   MK = MK / (CS + 1)
      :   REM   WEIGTED MEAN LENGTHS IN SPORT CATCH AND CREEL
--------------------
```

```
---------------------
2310      Z(3,TI) = INT (NO(0))
     :    Z(8,TI = INT (LS)
     :    Z(9,TI) = INT (CS)
     :    Z(17, TI) = MH
     :    Z(19,TI) = INT (LC)
     :    Z(21,TI) = INT (Z(19,TI) * WT)
     :    Z(24,TI) = Z(21,TI) / (Z(23,TI) + 1)
     :    Z(11,TI) = INT (WC)
     :    Z(18,TI) = MK
---------------------
2330      PRINT "ANGLER HOURS = " INT (Z(13,TI))
     :    PRINT "ANGLER CATCH = "Z(8,TI)
     :    PRINT "CREELED = "Z(9,TI);" (";Z(11,TI);" LBS)"
     :    PRINT "ACTUAL CREELED = " INT (Z(10,TI));" ("; INT (Z(12,TI))
             ;" LBS)"
---------------------
2340      PRINT "CATCH RATE = " FN RD(Z(14,TI))
     :    PRINT "CREEL RATE = " FN RD(Z(15,TI))
     :    PRINT "ACTUAL CREEL RATE = " FN RD(Z(16,TI))
---------------------
2350      PRINT "GILL NETTED = "Z(19,TI)
     :    PRINT "ACTUAL GILL NETTED = " INT (Z(20,TI))
     :    PRINT "SPAWNER ABUNDANCE = " INT (Z(4,TI))
     :    PRINT "NUMBER OF FRY = "Z(3,TI)
     :    PRINT "RECRUIT FUNC = "RE$
---------------------
8000      REM  BEGIN SIMULATION PLOTTING PROGRAM
```

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