PULSE FISHING OF A WALLEYE POPULATION: RESPONSE, RECOVERY AND MANAGEMENT IMPLICATIONS

by

Stephen Spencer

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DECLARATION

The research presented in this thesis was carried out by the author and has not been previously submitted for credit towards any degree or diploma. The work of others, where included, has been appropriately cited.

Abstract

The response of the Henderson Lake boreal fish community to a large scale exploitation of walleye was studied. The pulse fishery removed approximately 89 percent (3226) of adult walleye (1980-82) from Henderson lake during a period when recruitment was negligible. Following the exploitation, the ninespine stickleback, a major forage item, rapidly declined and by 1984 had apparently disappeared. By 1986 northern pike and yellow perch populations were increasing, two large yearclasses of young of the year walleye (in 1985-86) were also produced.

I expected that such an excessive harvest would have collapsed the walleye population. This would allow northern pike and yellow perch to increase in size and number with northern pike eventually becoming the sole top predator. Unsuccessful attempts to estimate adult walleye abundance in 1986, 1988 and 1991 seemingly supported the hypothesis that the population would not recover.

However, 1994 and 1995 population estimates showed that the walleye population had recovered to about 25 percent (871 fish) of pre-harvest numbers. In addition, the ninespine stickleback were once again caught in seine hauls. Northern pike numbers have declined from pre-harvest levels. Multimesh gillnet estimates of yellow perch catch per unit effort (CUE) indicated a decrease in abundance from levels measured in 1991.

Good indices for measuring population response (harvest effects and recovery) were: average length at age for younger walleye and northern pike, as well as changes in length distributions for both populations. Condition factor and length-weight data were poor indices and were not correlated to fish abundance. Schumacher-Eschmeyer estimates were not good indicators of population abundance during the harvest phase of the study where as six foot trapnet CUE followed actual adult walleye numbers throughout the study period.

A model predicting walleye abundance and time to recovery was employed. It included: 1984 population numbers, fecundity at age, pre-harvest estimates of mortality, weather data and age of recruitment to the gear to predict current abundance and time to recovery. Population numbers for walleye in years 1995 and 2003 were predicted at 1450 and 3280 fish, respectively. From this model I estimated it would take at least 20 years to mitigate the effects of a 90% removal of the adult stock. If pulse fishing is to be employed as a management technique, removal rates would have to be much lower.

Acknowledgments

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Introduction

Walleye (*Stizostedion vitreum vitreum*) and northern pike (*Esox lucius*), are popular sport fishes which coexist in northwestern Ontario lakes. Increased fishing pressure in concert with better road access often results in the excess harvest of these predatory species. Adaptive strategies may help management agencies avoid overharvest and sustain the fishing quality of such lakes.

Adams and Olver (1977) recommended that "pulse fishing" might serve as a possible management technique. Under this scheme, a short harvest period is followed by a moratorium on fishing. Pulse fishing remains a compromise between biological and economic considerations allowing the exploited species to recover while reducing expensive monitoring by management agencies (Adams and Olver 1977). In Henderson Lake a pulse fish harvest of walleye from 1980 to 1982 removed 89 percent of the adult fish (Reid and Momot 1985). Concurrent recruitment failure helped reduce the population to a level too low to estimate by the Schumacher-Eschemeyer mark and recapture method (Schumacher and Eschmeyer 1943). During the 3 year period of exploitation approximately 5 kg/ha per year was removed for a total of 15 kg/ha. This exceeded the recommended Ontario commercial fishery management guideline of 0.94 kg/ha per year by 500 percent, and the angling fishery management guideline by 333 percent (OMNR 1982).

In fish communities, where the target species presumably overlap in their dietary habits, the removal of one may effect the population level of the other. An example of potential competitors would be two species sharing dietary components (Johnson 1977). In Henderson Lake both northern pike and walleye occupy the same trophic level as terminal predators depending heavily on the same type and sizes of prey throughout the year (Reid and Momot 1985). In such cases differences in diel activity patterns (Ryder and Kerr 1978), or weather conditions often serve to partition food resources between these species.

The response of walleye and northern pike populations to harvest has been studied independently on many different water bodies. The development of predictive management strategies is confounded by between lake differences, such as the amount and type of vegetation, food availability, water clarity, and lake size. This study attempted to document and predict the simultaneous response of both populations following an excessive pulse harvest of one species, the walleye. It also addressed the following concerns should a large removal of walleye occur: (1) Would the northern pike permanently displace the walleye? (2) How would other components of the fish community respond? (3) Would walleye recover to preharvest numbers? (4) What level of harvest would allow walleye to recover more quickly? (5) Whether or not pulse fishing is a viable management technique for northern Ontario walleye lakes?

Study Area

Henderson Lake is located approximately 135 kilometres northwest of Thunder Bay, Ontario (Fig. 1). It was a designated provincial fish sanctuary in 1969 for the purpose of experimental research (Reid and Momot 1985). Henderson Lake has intermittent inflows and outflows and with the possible exception of white suckers (*Catostomus commersoni*) remains an isolated system since most species studied cannot immigrate or emigrate over or through the beaver dams (Fig. 2). Henderson is small (150.9 ha) and relatively shallow lake. It has a mean depth of 2.5 m, a maximum depth of 6.5 m, is 3.0 km long with a maximum width of 1.0 km. In the deeper

Figure 1. Location of Henderson Lake in the study area.

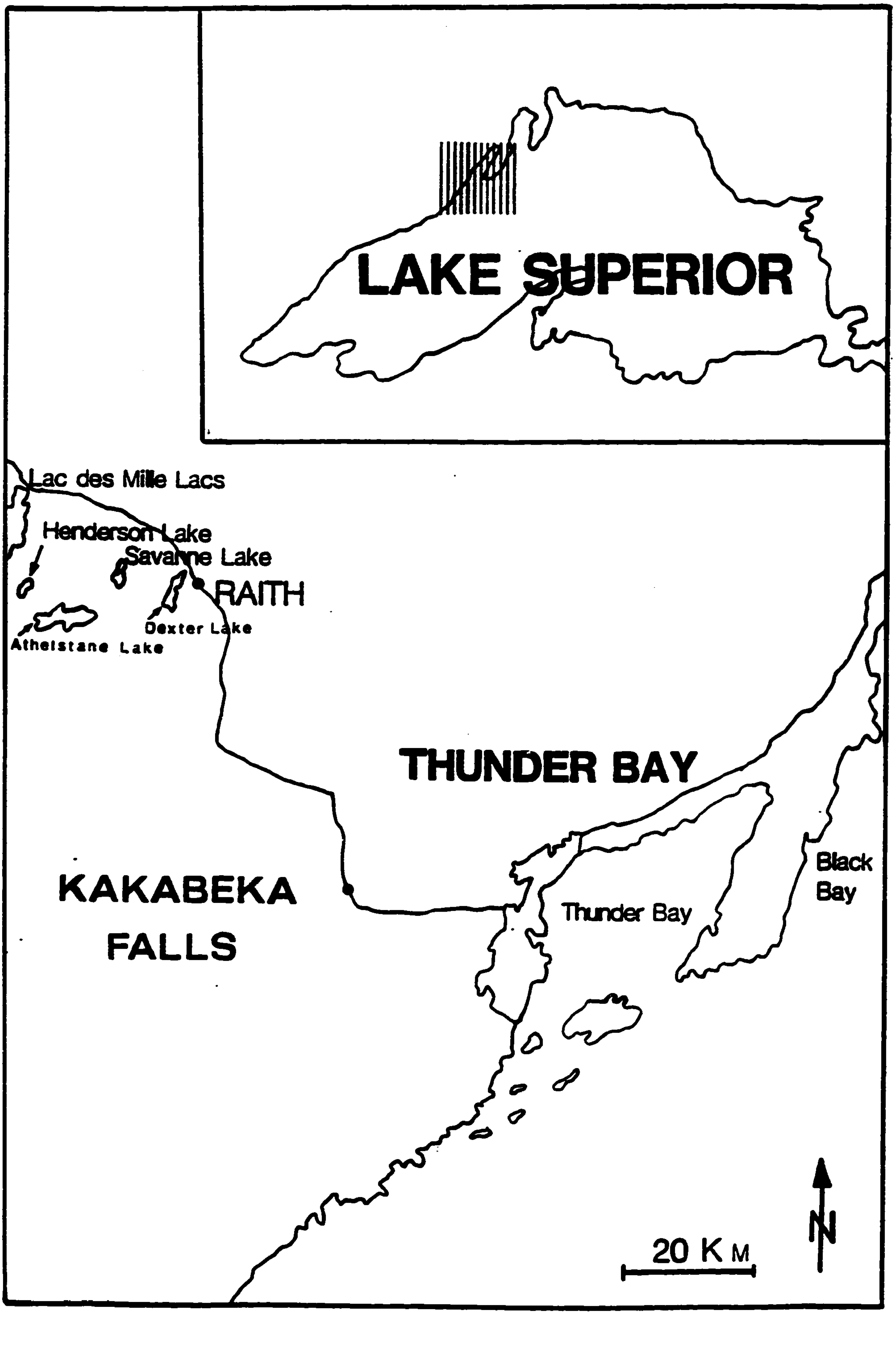
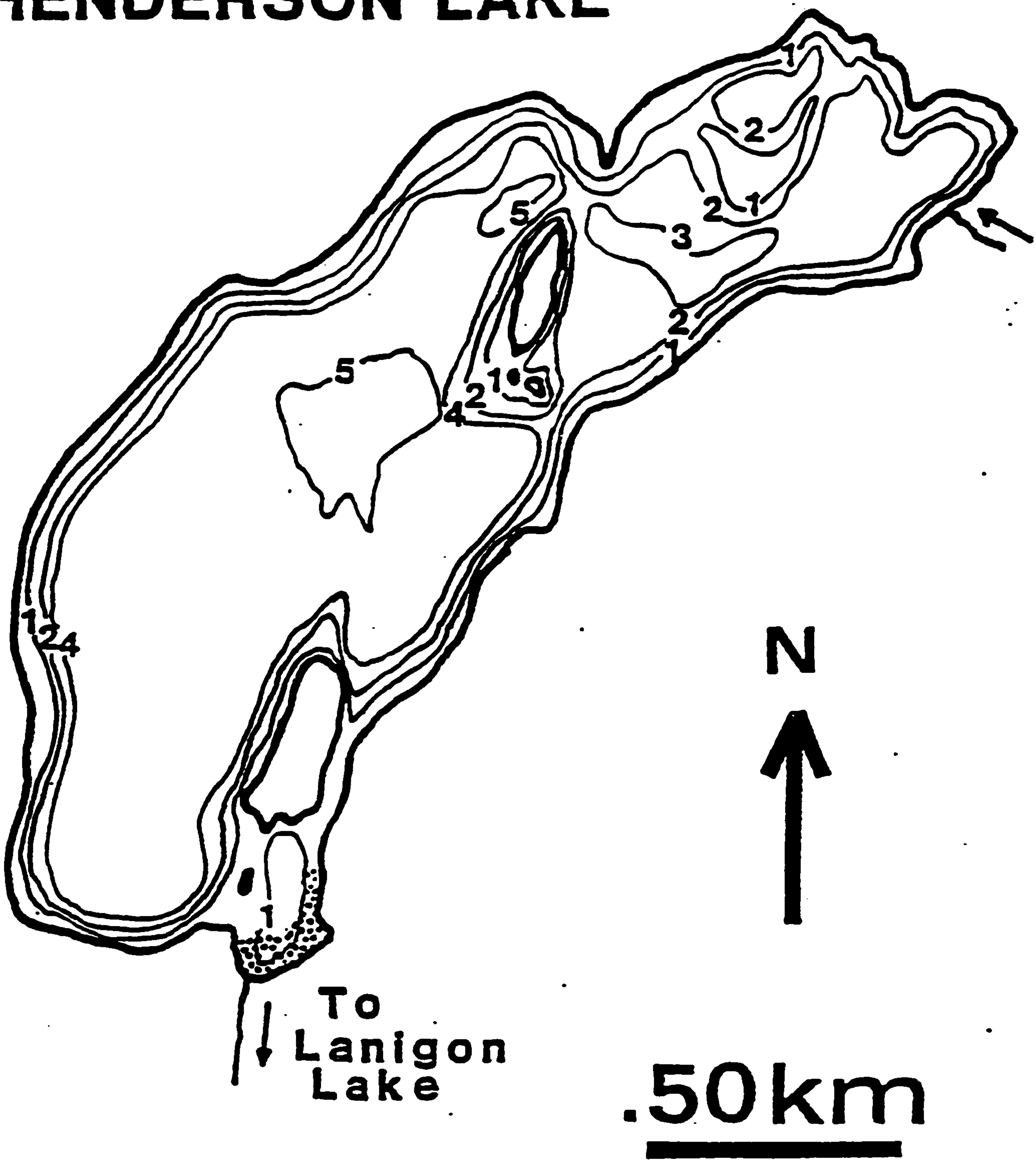

LAKE SUPERIOR
Lac des Mille Lacs
Henderson Lake
Savanne Lake
RAITH
Dexter Lake
Athelstane Lake
THUNDER BAY
KAKABEKA
FALLS
Thunder Bay
Black
Bay
20 KM
N

Figure 2. Henderson Lake depth contours in metres.

HENDERSON LAKE



areas the bottom consists of mud with shallower areas covered with dense emergent and submergent vegetation.

Henderson Lake supports nine fish species: northern pike, walleye, white sucker, yellow perch (*Perca flavescens*), burbot (*Lota lota*), ninespine stickleback (*Pungitius pungitius*), mimic shiner (*Notropis volucellus*), blacknose shiner (*Notropis heterolepis*) and Iowa darter (*Etheostoma exile*).

Henderson Lake is homothermous with recorded summer temperatures reaching 26 ^{0}C throughout the water column. The Morphoedaphic Index (MEI) index classifies the lake as slightly eutrophic (Adams and Olver 1977). Major physical and chemical characteristics of Henderson Lake are listed in Table 1.

Harvest History

Prior to harvesting, abundance of fish amenable to trapnets (4ft, 6ft and 8ft Lake Erie design trapnets) was estimated in the springs of 1979 and 1980 (Nunan 1982). Walleye were removed during the fall with both multimesh experimental gillnets and trapnets. The initial harvest in 1980 removed 84% of the estimated population (1332 walleye averaging 0.614 kg, Nunan 1982). Surprisingly, the 1981 spring Schumacher-Eschmeyer estimate deviated only 11% and 26% from the 1979 and 1980 estimates, respectively (Reid 1985). The previous population estimates were deemed inaccurate so an additional 1115 walleye (averaging 0.770 kg each) were removed in 1981 (Nunan 1982). The 1982 harvest of 779 walleye (averaging 0.822 kg each) caused an unplanned collapse of the stock (Reid 1985). Concurrent and subsequent years of recruitment failure reduced adult walleye numbers sufficiently to prevent further multiple mark and recapture estimates by 1986 (Wisenden 1988).

Table 1. Chemical characteristics of the surface water in Henderson Lake from 1973 to 1995

Parameter	May 73[1]	July 80[1]	Aug 84[2]	July 86[3]	Mar 87[3]	Nov 94	Aug 95
Conductivity (µS/cm)	38.0	49.0		42.0	48.0	44.0	45.0
Total Dissolved Solids (TDS)	40.0	41.0	40.1	40.0	53.8[4]	52.0[4]	52.5[4]
Morphoedaphic index (MEI)[5]	16	16	16	16	22	21	21
pH	7.2	7.5		7.5	7.0	7.5	8.0
Alkalinity as $CaCO_3$ (mg/L)	14.0	20.0	18.5	19.0	21.0	21.0	22.0
Colour (true colour units)					7.0	7.9	16.0
Turbidity (FTU)[6]	2.00	0.75		1.20	0.25	1.70	3.50
Nitrogen (kjeldahl mg/L)			0.510	0.410	0.350	<0.001	0.010
Sulphate (mg/L)						2.10	1.33
Calcium (mg/L $CaCO_3$)			5.5	4.7	5.4		5.8
Magnesium (mg/L)			1.9	1.6	1.8		1.8
Total Phosphorus (mg/L)			0.001	0.015	0.006	0.014	0.017
Secchi (m)			2.8	2.5			
Hardness (mg/l of $CaCO_3$)	14.0	20	22	18		21	22

[1] Nunan 1982
[2] Reid 1984
[3] OMNR unpublished data
[4] TDS=33.026+ .43232* conductivity (T. Marshall, O.M.N.R. Researcher, 1995,Pers. Comm.).
[5] M.E.I.=T.D.S./ mean depth
[6] Formazine turbidity units

The first indication that walleye might recover came in 1985 and 1986 with the discovery of numerous young of the year (YOY) in beach seines (Wisenden 1988). However, an attempted spring mark and recapture estimate in 1988 followed in 1991 by a late summer experimental gillnetting gave no indication of any recovery (unpublished data).

Between 1980 and 1985, 1000 northern pike (2 kg/ha/year) were removed from Henderson Lake for research purposes and by incidental gillnetting for walleye. Northern pike production dramatically increased following the 1980-82 walleye harvest and by 1986 their numbers appeared to be increasing (Wisenden 1988).

Methods and Materials

Sampling Techniques

During the spring of 1994 and 1995 the population size of walleye and northern pike vulnerable to the gear was estimated using both the Schumacher-Eschmeyer and the Schnabel multiple mark and recapture methods (Ricker 1975). In 1994 fish were captured using two 1.2 m (four foot Wisconsin style) fyke nets and two 1.8 m (six foot) trapnets for an effort of 3614 hours consisting of 70 sets. In 1995, one fyke net and three trapnets were used for a total effort of 100 sets and 4108 hours. The nets set initially on June 8, 1994 and May 6, 1995 were frequently moved to sample various habitats including previous sites. Both major predator species, plus common sucker, were marked by clipping the left and right pectoral fins in 1994 and 1995 respectively. Included in this study were data from a 1988 spring sample consisting of 19 sets, totaling 549 hours, with two trapnets and one fyke net (unpublished data).

Relative abundance of walleye, northern pike, white sucker, and yellow perch were determined by using a 122 meter multimesh experimental gillnets (consisting of 8, 15m long panels of 38mm, 51mm, 64mm, 76mm, 89mm, 102mm, 114mm and 128mm stretched mesh). These nets were set six times for a total of 15.5 hours during August 17th and 18th. The sets were of short durations (less than three hours) and when the water was below 17 ^{0}C to avoid mortalities. Comparisons of catch per unit effort (CUE) were made with a 1991 gillnet study using the same gear and consisting of 6 sets totaling 22 hours (unpublished data). In 1995, an additional fine mesh gillnet was used to capture younger fish. This net consisted of three 15 meter panels, two of 1 inch (2.5 cm) and one .75 inch (1.9 cm). It was set 8 times (totaling 29 hours) at various light intensities and at depths varying from 0.5 m to 6.5 m.

In both 1994 and 1995 near shore fish collections were made in July and August using a bag seine. The seine dimensions were 18.3 m (60 ft) long, 1.2 m (4 ft) wide with a 3.2 mm square mesh bag and 6.5 mm mesh wings. The net was laid out parallel to shore, at a distance of 30.5 m (100 ft) and drawn towards shore thus each sample encompassed 0.047 hectares of the littoral zone. Seining occurred during daylight and after dark consisting of 13 and 22 hauls in the first and second year respectively. All species captured were counted and a subsample measured. Northern pike, common white sucker, burbot and walleye were recorded as YOY, juvenile or adult. Because the yellow perch are stunted in Henderson Lake, separation by length into different age classes was not feasible (Ritchie 1984).

Limited angling (35 rod-hours) conducted in both 1994 and 1995 between June and September allowed the collection of stomach samples, calcified tissues and the comparison of angling success with other lakes.

Sampling of Fish

All fish were measured for total length to the nearest millimeter, weighed to the nearest gram, and aging materials were collected from representative one centimeter subsamples. Northern pike scales were taken from above the lateral line, anterior to the dorsal fin on the left side of the fish in 1994 and from the same area on the right side of the fish in 1995 (Laine et al. 1991). Scales from walleye were taken from behind the pectoral fin on the left side of the fish in 1994 and on the right side in 1995 (Baccante and Sandhu 1983). The opercles from walleye and cleithra from pike were taken from dead fish for scale ageing verification. Fish were sexed externally during spawning based on extrusion of sex products.

Scales of both northern pike and walleye were rolled on acetate slides and read on a microfiche projector. Scales were aged using standard procedures, (Casselman 1978a, Baccante and Sandhu 1983) and verified by Jon George (Q.M.L. FAU Senior Technician 1994) and Susan Mann (O.M.N.R. ageing specialist).

Environmental Data

Surface and bottom water temperatures were recorded at each net lift. Thunder Bay weather records were used to calculate growing degree days above five degrees Celsius (Environment Canada, Weather Records 1949-1995). Weather records from Thunder Bay (115 km from study site) closely approximated (r^2=0.98) the nearby Raith weather station (11 km distance) which closed in 1984. The following equation was employed to adjust for the difference between the two stations for missing Raith records: $Y=0.89X-8.8$, where X represents the Thunder Bay temperature and Y the corrected temperature.

Data Analysis

Age distributions of walleye, northern pike and white sucker for 1988 (unpublished data), 1994 and 1995 were calculated from subsamples of fish (excluding any recaptures) caught during spring trapnetting (Ketchen1949). Length-weight least-square regressions were computed for walleye and northern pike each spring (1994 and 1995) using a $\log_{10}$-$\log_{10}$ transformation. Covariant analysis tested between year differences for length-weight regressions (Sokal and Rohlf 1981). Between year differences in age-class lengths were compared using T-tests (Sokal and Rohlf 1969). Back calculation of length at age, and annual growth were computed using the University of Minnesota's F.I.S.H. age analysis software (Weisburg 1989).

Condition factors (K) were calculated using: $K = W/L^3 \times 10^6$ (Bagenal and Tesh 1978), where W and L are weight (grams) and length (centimeters). Statistical comparison of K values were made using the T-test (Sokal and Rohlf 1981), unless stated otherwise.

All data collected is available at the Quetico Mille Lacs Unit, Ontario Ministry of Natural Resources, 25th Side Road, Thunder Bay, Ontario.

Population Prediction Model

I tried to predict the population size of walleye in 1995 and time to recovery using 1979 to 1986 data (Nunan 1982, Reid 1985, Wisenden 1988). Two variations of a mechanistic model were employed. Both variations were extrapolated from 1984 population data including; estimates of mortality, age to fecundity relationships, size at age estimates, Von Bertanlanffy's growth equation and the remaining number of fish in each age category (N. Baccante O.M.N.R. Biologist, Nunan 1982, Reid 1985, Ricker 1975). Variation A used a constant survival rate while variation B allowed for a 0.01 percent increase in egg survival during warmer than the mean years (1987, 1988, 1991, 1994 to 1996) which favor YOY production (Ritchie and Colby 1988). The number of eggs (E) produced per year-class was represented as: $E = Nf(23251+6442A)$, where Nf is the number of mature females, A is the age of the fish and 23251+6442A is the fecundity relationship at various ages. Age fecundity relationships were calculated from 66 fish captured from 1982 to 1984 and weighted according to annual sample size (Reid 1985). The number of fish in a year-class (Ny) was determined by: $Ny = No(1-Z)$, where No is the number of fish or eggs from the previous year-class and Z is the total mortality for that year-class.

For comparison of predicted results to Schumacher-Eschmeyer estimates, I plotted age of fish recruited to the gear against the age of fish estimated by the model. From the difference between the two I was able to plot a line which estimated the percent recruitment for the younger fish.

All data are from Henderson Lake with the exception of mortality estimates of YOY to age of total recruitment (at 6 years old) which were taken from nearby Savanne Lake (Baccante and Colby 1996). The model is based on the following assumptions:

1. Maximum egg production is 230 000 ha^{-1}, similar to nearby Savanne Lake (Baccante and Colby 1996),
2. 50 percent of the adult population is female.

This model will give an additional check on population numbers, predict a time to recovery and help evaluate whether the Pulse fishing technique is a viable management tool for a northern boreal lake.

Results

Population Estimates

Schumacher-Eschmeyer multiple mark and recapture estimates of walleye were 772 in 1994 and 871 in 1995 (Fig. 3). The Schnabel method, with the same population data, estimated 779 and 609 walleye in 1994 and 1995 respectively. Walleye were more susceptible to the deeper set trapnets (Fig. 4).

The Schmacher-Eschmeyer population estimates for northern pike were 1537 and 934 while the Schnabel estimates were 1612 and 712 in 1994 and 1995 respectively. The shallower set fyke nets were more effective at catching northern pike than the trapnets.

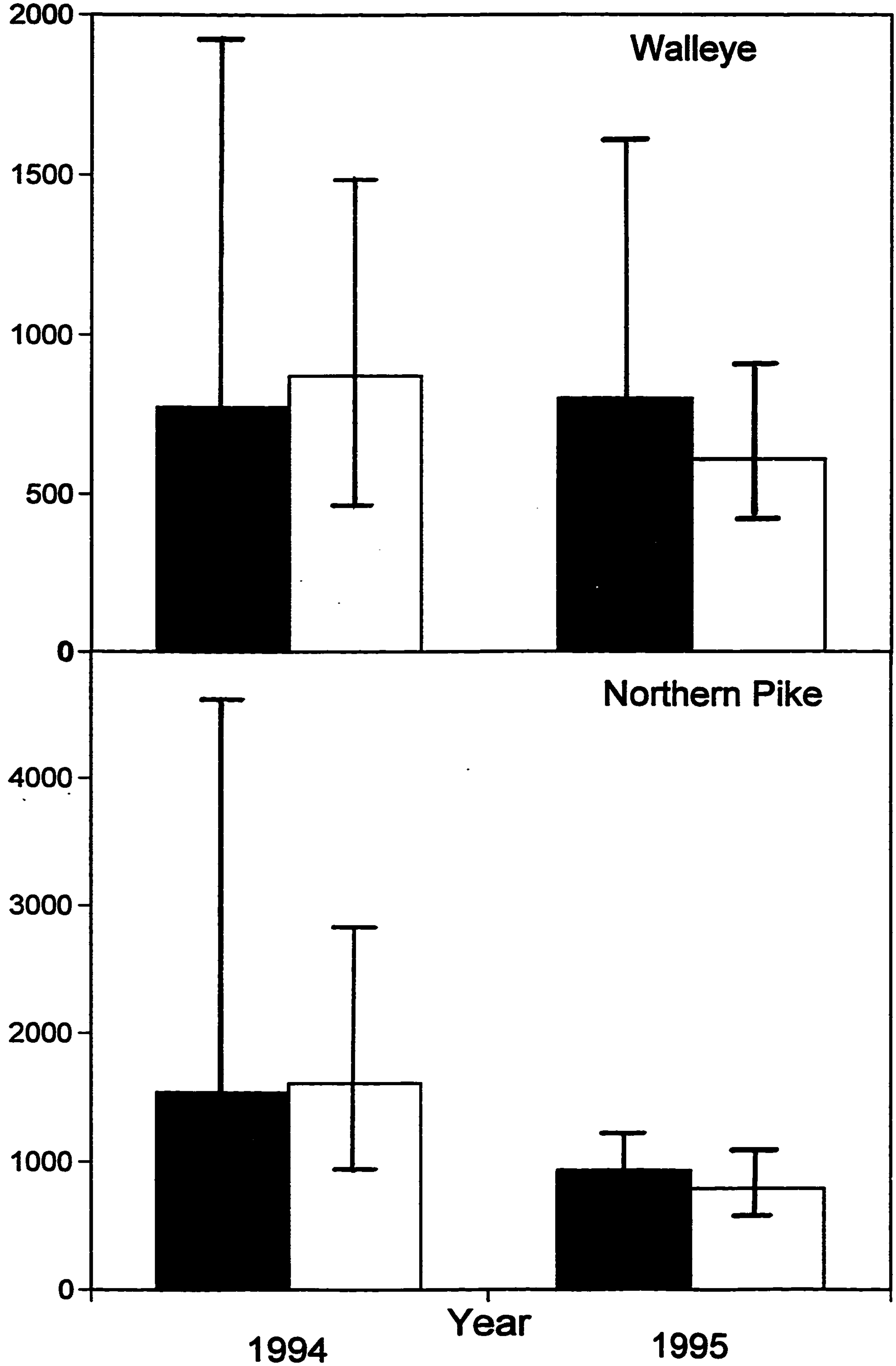
The Schnabel mark and recapture method differed from the Schmacher-Eschmeyer by 3.5 and 30 percent for walleye and 4.9 and negative 15.2 percent for northern pike in 1994 and 1995 respectively. Although the 1995 differences were considerable, all Schnabel estimates fell within the confidence limits of the Schmacher-Eschmeyer estimates. The confidence limits for the 1995 estimates were more precise than those in 1994 and likely due to an earlier start and higher effort.

Multiple mark and recapture population estimates of adult white suckers were not possible because of their relatively low vulnerability to the gear during spring sampling.

Relative Abundance

The fall experimental gillnet CUE increased for walleye from 0.22 (s^2=0.54) to 1.24 (s^2=0.58) fish per hour in 1991 and 1994 respectively (Fig. 5). From 1994 to 1995 walleye angling CUE increased as well. The following is a summary total of effort (number of rod hours) and angling catch per unit effort (fish per rod hours) on Henderson Lake:

Figure 3. Schumacher-Eschmeyer (dark bar) and Schnabel (light bar) population estimates for Henderson Lake walleye and northern pike. Error bars indicate 95% confidence levels.



2000
1500
1000
500
0
Walleye
Northern Pike
4000
3000
2000
1000
0
Year
1994
1995

Figure 4. Hoopnet versus trapnet comparison of CUE (number of fish per hour) in Henderson Lake, Ontario

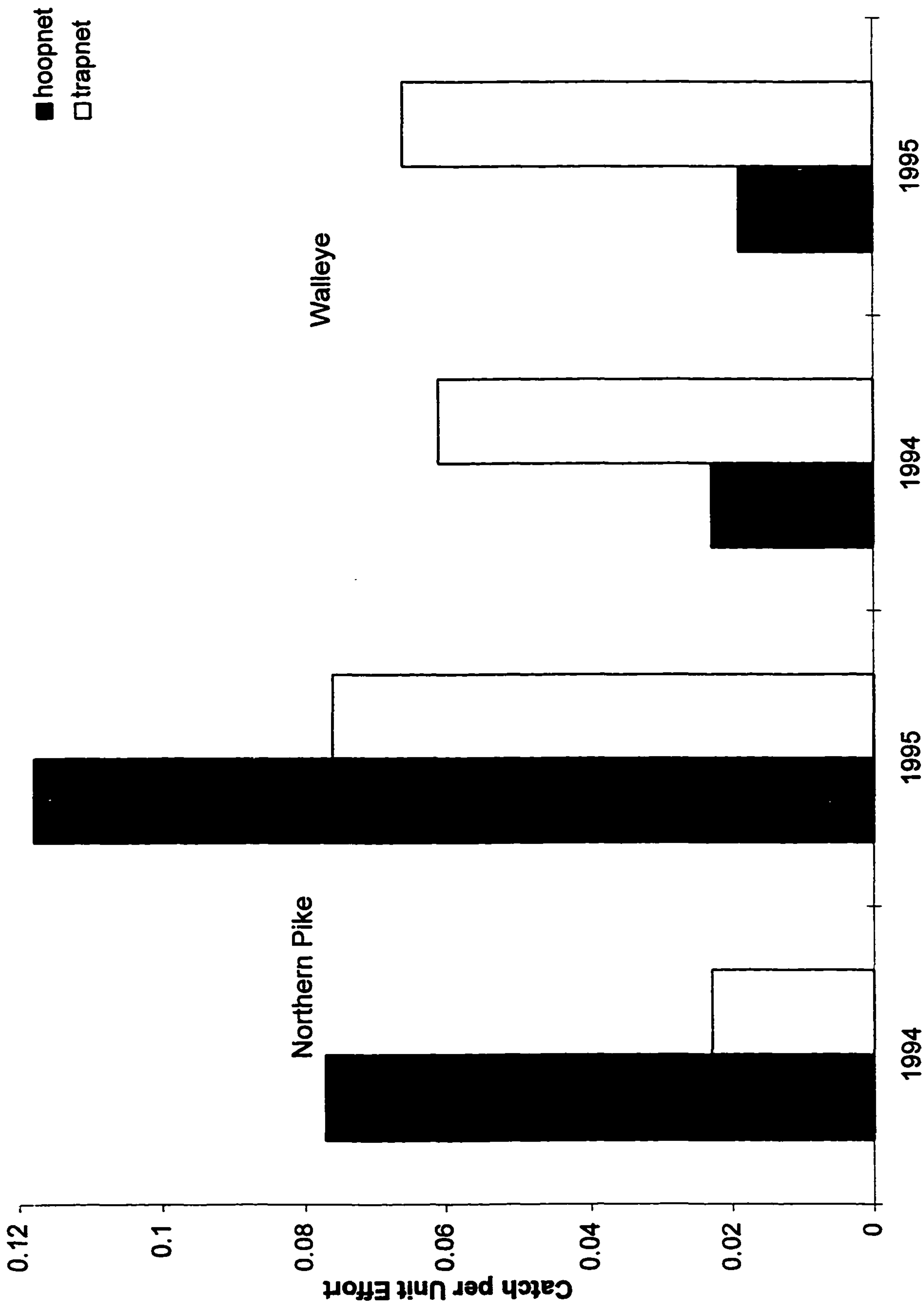
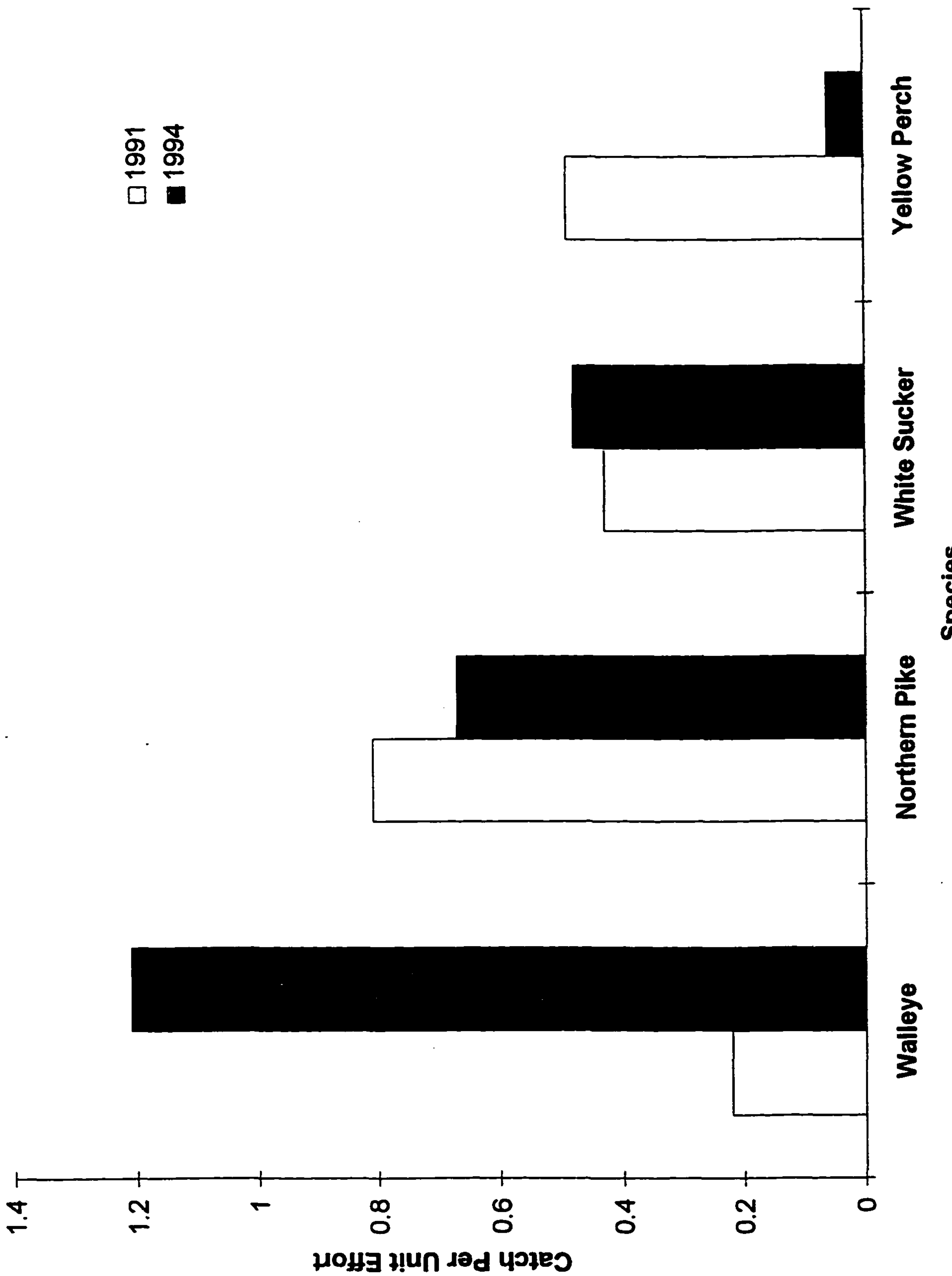

hoopnet
trapnet
Northern Pike
Walleye
1994
1995
1994
1995
Catch per Unit Effort
0
0.02
0.04
0.06
0.08
0.1
0.12

Figure 5. Experimental gillnet CUE for different species in Henderson Lake during 1991 and 1995.


Catch Per Unit Effort
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Walleye
Northern Pike
White Sucker
Yellow Perch
Species
1991
1994

Year	Walleye (Fish per rod hour)	Northern Pike (Fish per rod hour)	Effort (Number of rod hours)
1994	0.68	1.72	20
1995	0.99	2.85	15

Improved walleye angling from 0.68 fish per rod-hour in 1994 to 0.99 in 1995 may reflect the increase in population size.

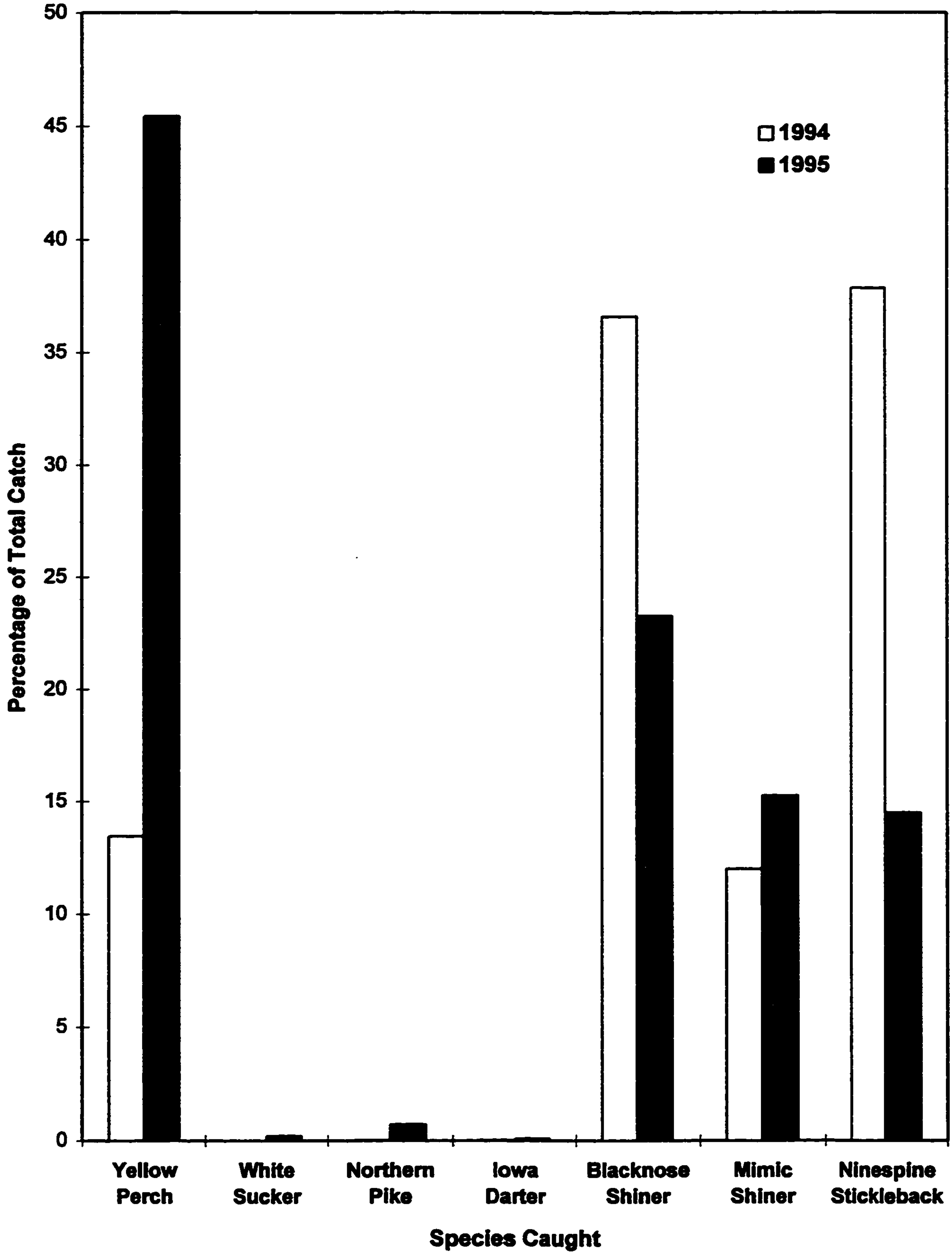
The number of northern pike caught also increased from 1.72 (fish per rod-hour) in 1994 to 2.85 in 1995, while their abundance declined. The experimental gillnet CUE suggest a decline in abundance between 1991 and 1994 decreasing from 0.97 (s^2=0.69) to 0.55 (s^2=0.56) fish per hour respectively.

Yellow perch experimental gillnet CUE decreased from 0.49 (s^2=0.62) in 1991 to 0.06 (s^2=0.13) in 1994. White sucker CUE varied little from 1991 (0.44, s^2=0.94) to 1994 (0.57, s^2=0.75).

Near Shore Seining

Ninespine sticklebacks were caught in 1994 for the first time since 1983 (Fig. 6). The ninespine stickleback tended to be more susceptible to seining at low light intensity or after dark (T-test, $P>0.05$ pooled df=34). Seine catches of the ninespine stickleback fluctuated considerably from 652 to 0 fish per haul. There was a significant decrease in the number of ninespine sticklebacks per seine haul (175 in 1994 to 46 in 1995, T-test, $P<0.05$ pooled df=34).

Figure 6. Composition of the seine catch in Henderson Lake (1994 and 1995).



50
45
40
35
30
25
20
15
10
5
0
Percentage of Total Catch
1994
1995
Yellow Perch
White Sucker
Northern Pike
Iowa Darter
Blacknose Shiner
Mimic Shiner
Ninespine Stickleback
Species Caught

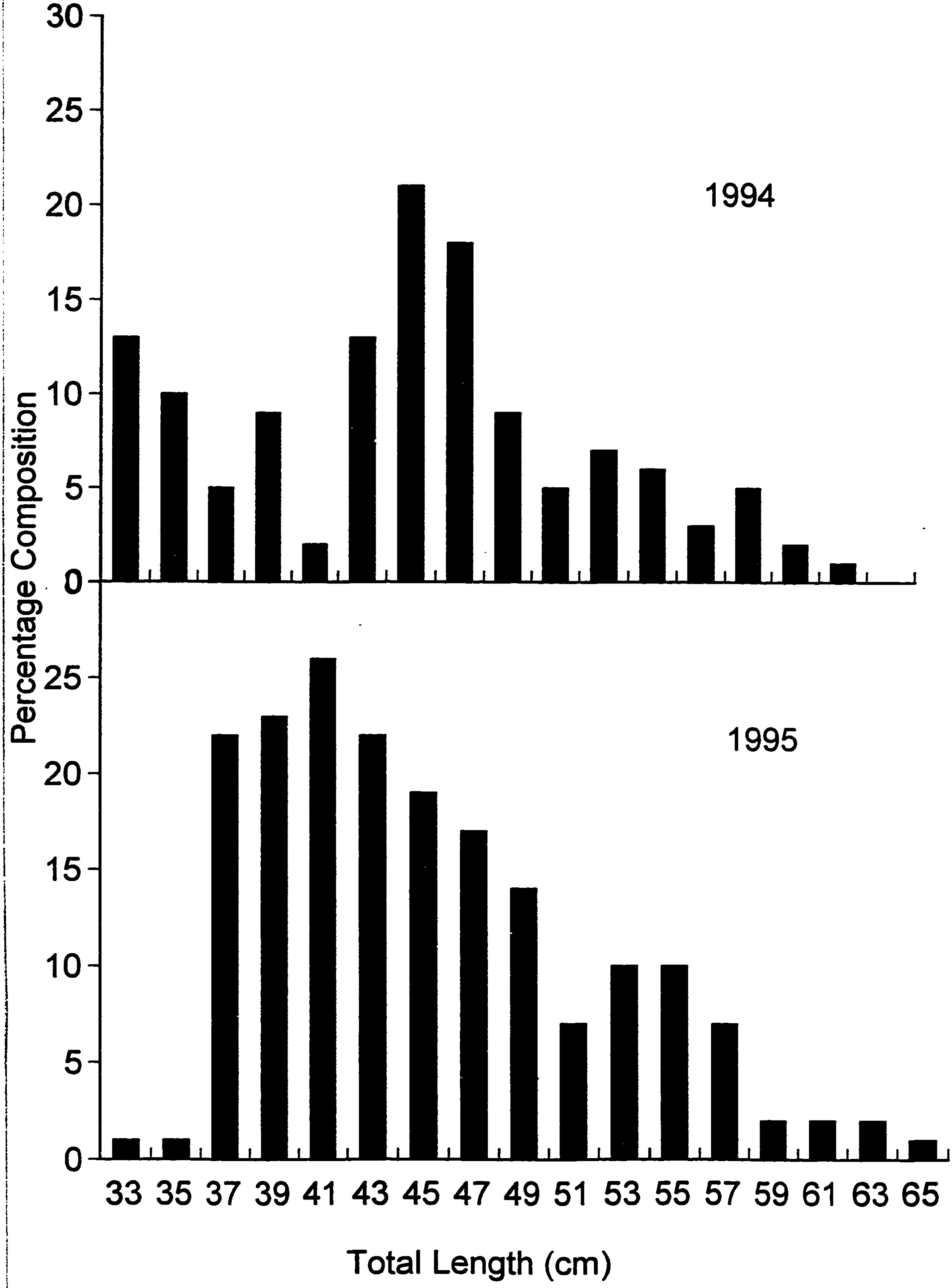
While the ninespine stickleback was the most abundant species in the seine nets for 1994 the yellow perch dominated the catch in 1995. Yellow perch increased from an average of 62 per haul in 1994 to 75 in 1995 (T-test, $P>0.05$ pooled df=32). During the same period blacknose and mimic shiners decreased from a mean of 169 to 39 and 56 to 25 per haul respectively. Meanwhile, the respective number of YOY northern pike and white sucker increased from 1 to 24 and 0 to 3. No YOY walleye and only one Iowa darter were caught during seining.

Age and Length Analysis

Length distributions of walleye in 1994 were trimodal (Fig. 7). The first mode comprised of an abundance of 3 and 4 year old recruits entering the fishery at total lengths of 33 to 38 centimetres (Fig. 8). The middle mode included ages 6 to 8 and ranging in total lengths from 43 to 49 centimetres. The last elongated peak contained several year-classes of fish greater than 51 centimetres. These were mostly fish older than age eight (Fig. 8). In 1995 the total length distributions were bimodal with total recruitment to the first mode comprising younger fish observed in 1994. The first and largest mode in 1995 included walleye of lengths 37 to 49 centimetres. The second mode consisted of fish larger than 51 centimetres with most older than age eight. Strong walleye year-classes present in the 1995 age distributions occurred in 1987, 1988 and 1990. For both 1994 and 1995 the spring captured walleye had a mean age of 6.6 years. Backcalculations of 1994 scale growth intervals indicated that walleye grew faster during 1987 (T test, $P<0.05$, df=52) and 1988 (T test, $P<0.05$, df=65).

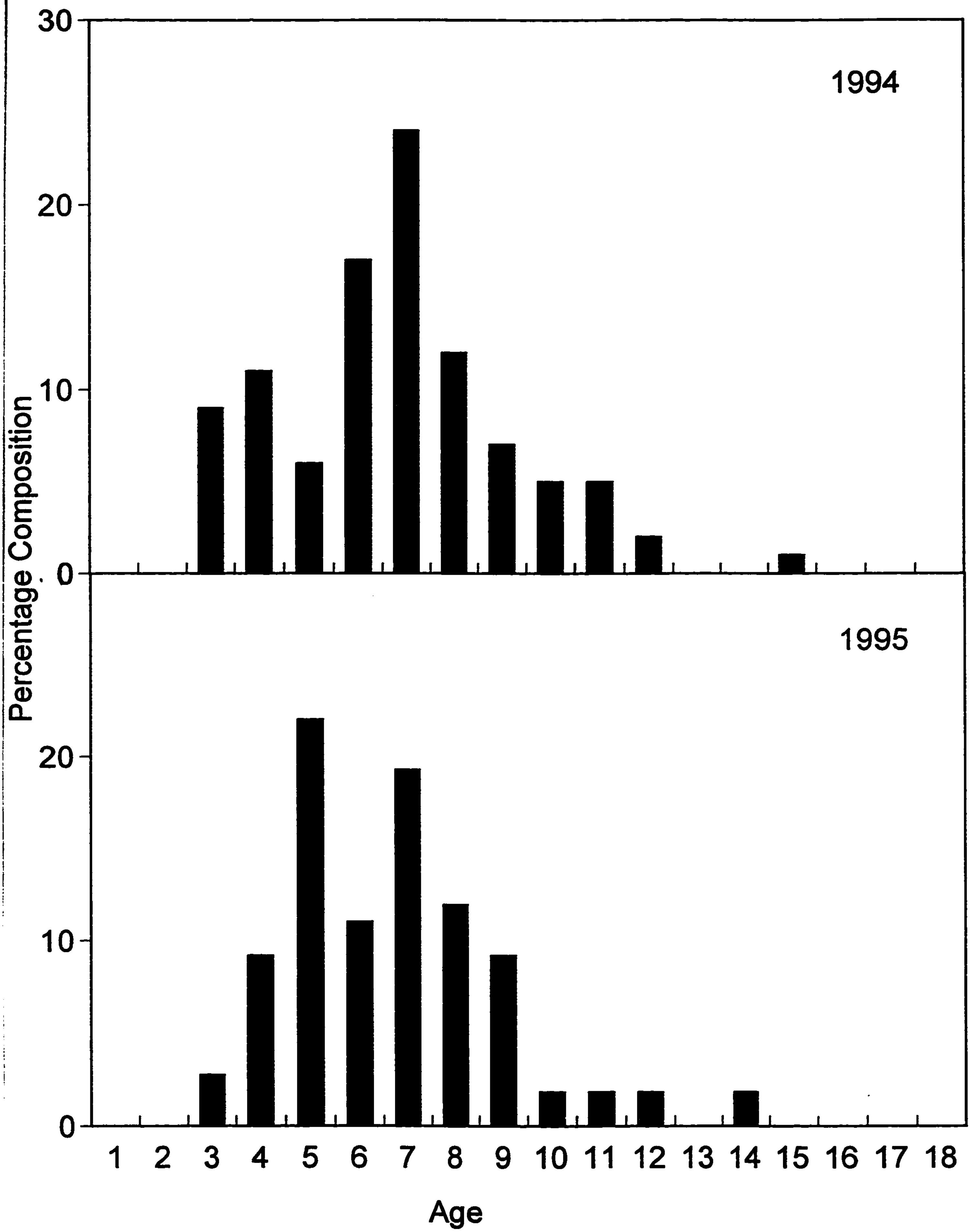
The majority of northern pike had total lengths between 45 and 75 centimetres in 1988, 1994

Figure 7. Length distribution of walleye in Henderson Lake (N=139 in 1994 and N=219 in 1995).



30
25
20
15
10
5
0
25
20
15
10
5
0
1994
1995
Percentage Composition
33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65
Total Length (cm)

Figure 8. Age distribution of walleye in Henderson Lake (N=100 in 1994 and 109 in 1995).



30
20
10
0
1994
1995
Percentage Composition
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Age

and 1995 (Fig . 9). Compared to 1988, there was an increase in fish over 90 centimetres in total length in both 1994 and 1995. Both 1989 and 1990 produced strong northern pike year-classes (Fig. 10). The mean age of northern pike decreased (T test, $P>0.05$ df=620) from 5.5 years in 1994 to 5.2 years in 1995. Backcalculation of 1995 scales showed northern pike grew significantly faster during 1990 (T test, $P<0.001$, df=56).

White sucker total length distributions shifted to the right from 1988 to 1995 indicating an increase in average length (Fig. 11). Most fish were between 41 and 51 centimetres total length in 1988 while increasing to 51 and 59 centimetres in 1995. White sucker length distributions for 1988 and 1995 are given. The 1994 distributions were omitted since only seven were caught.

Growth and Condition

At a given length, both walleye and northern pike weighed less in 1995 than in 1994. Analysis of covariance of the length weight regressions for both species revealed significant F values ($P<0.01$) for both slope and intercepts between years. The regression lines are as follows:

Year	Walleye	Northern Pike
1994	$\log_{10}W = 2.57 \times \log_{10}L - 3.80$ (r=.97, df=102)	$\log_{10}W = 2.67 \times \log_{10}L - 4.20$ (r=.96, df=98)
1995	$\log_{10}W = 2.85 \times \log_{10}L - 4.62$ (r=.93, df=101)	$\log_{10}W = 2.64 \times \log_{10}L - 4.27$ (r=.94, df=105)

Walleye and northern pike length at age did not differ significantly from 1994 to 1995 (T-test $P>0.05$). However the condition (K) for both species was less in 1995. The mean condition of

Figure 9. Length distribution of northern pike in Henderson Lake (N=166 in 1988, 191 in 1994 and 359 in 1995).

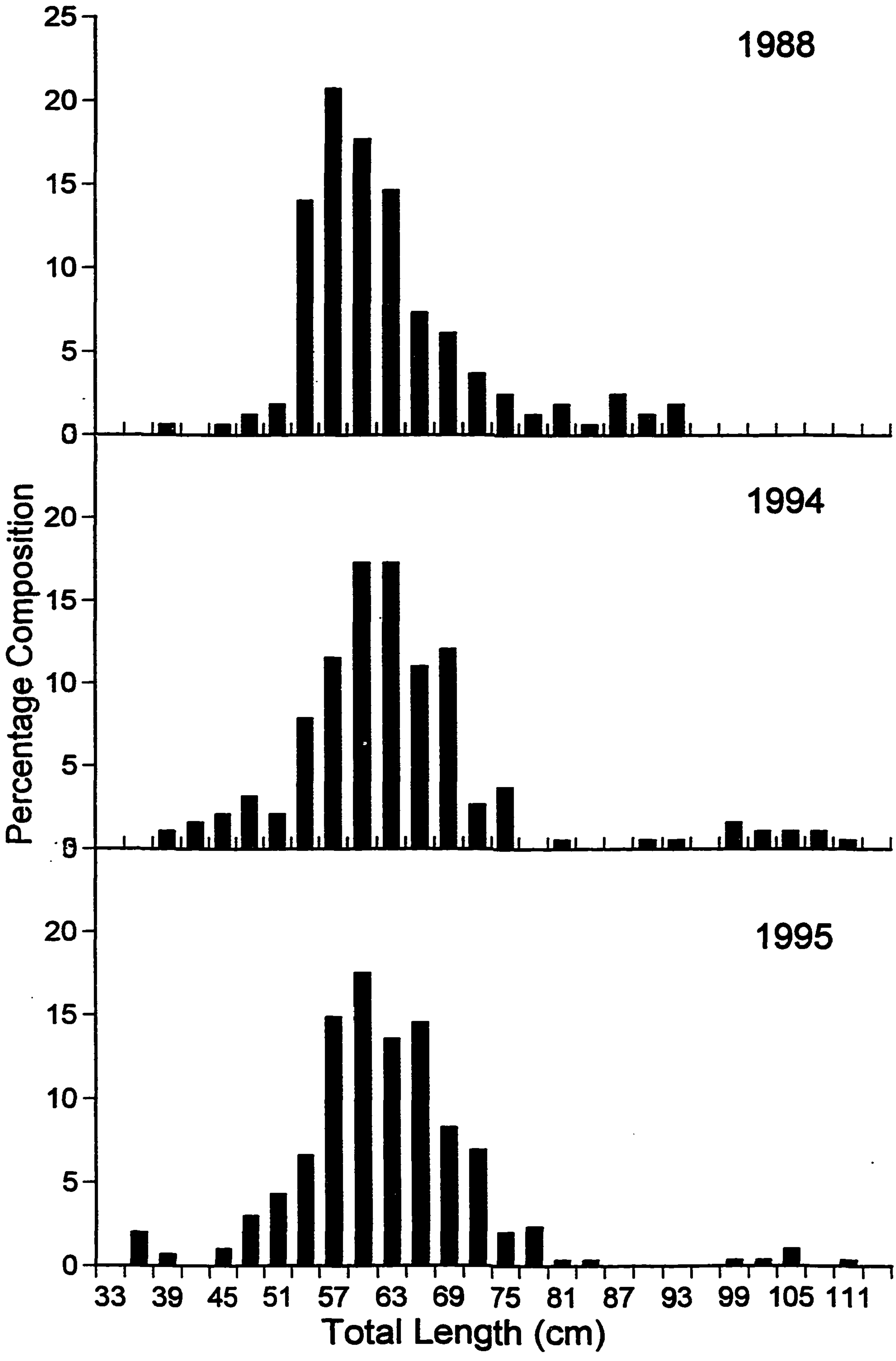

1988
1994
1995
Percentage Composition
0
5
10
15
20
25
33
39
45
51
57
63
69
75
81
87
93
99
105
111
Total Length (cm)

Figure 10. Age distribution of northern pike in Henderson Lake (N=100 in 1994 and 108 in 1995).

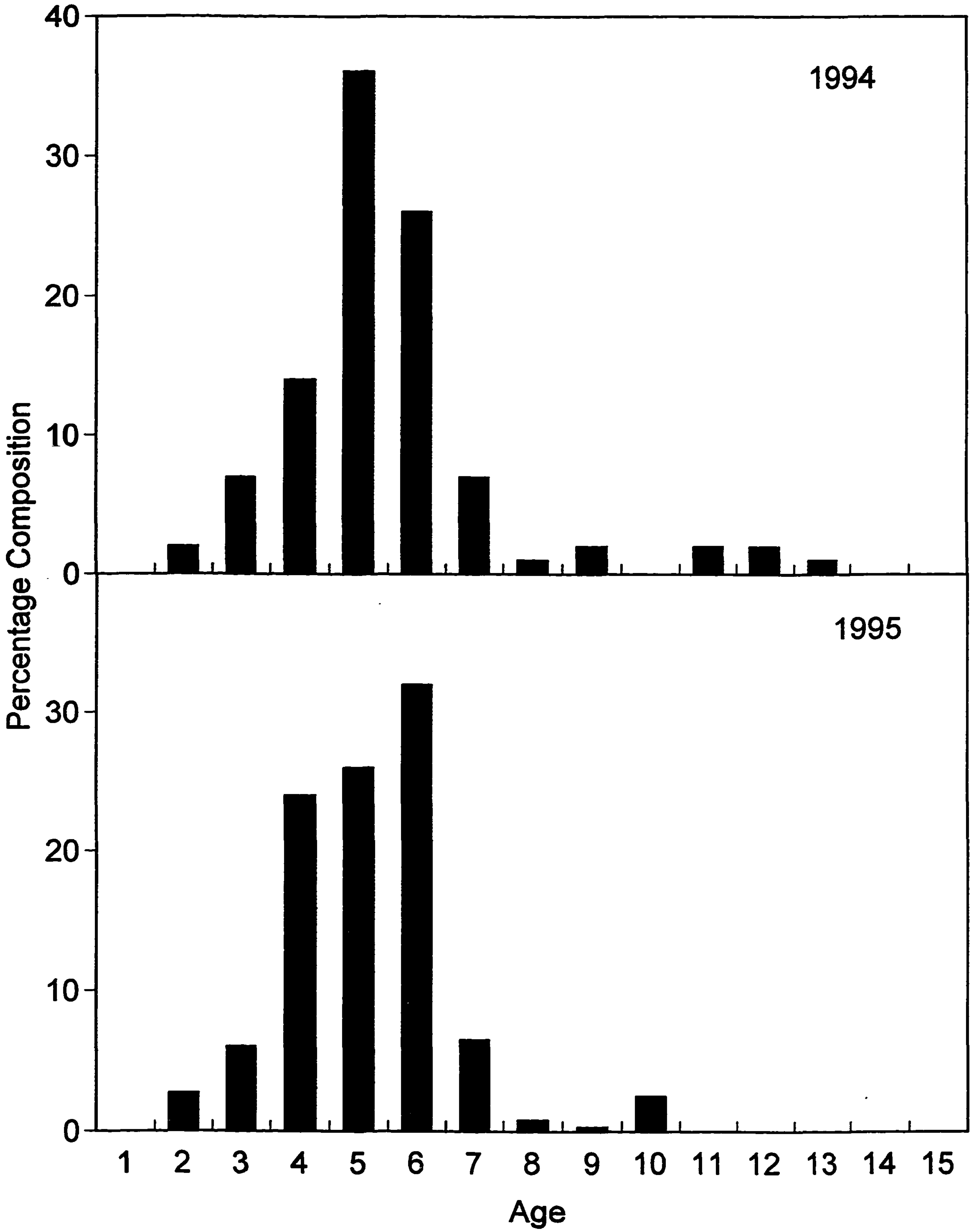
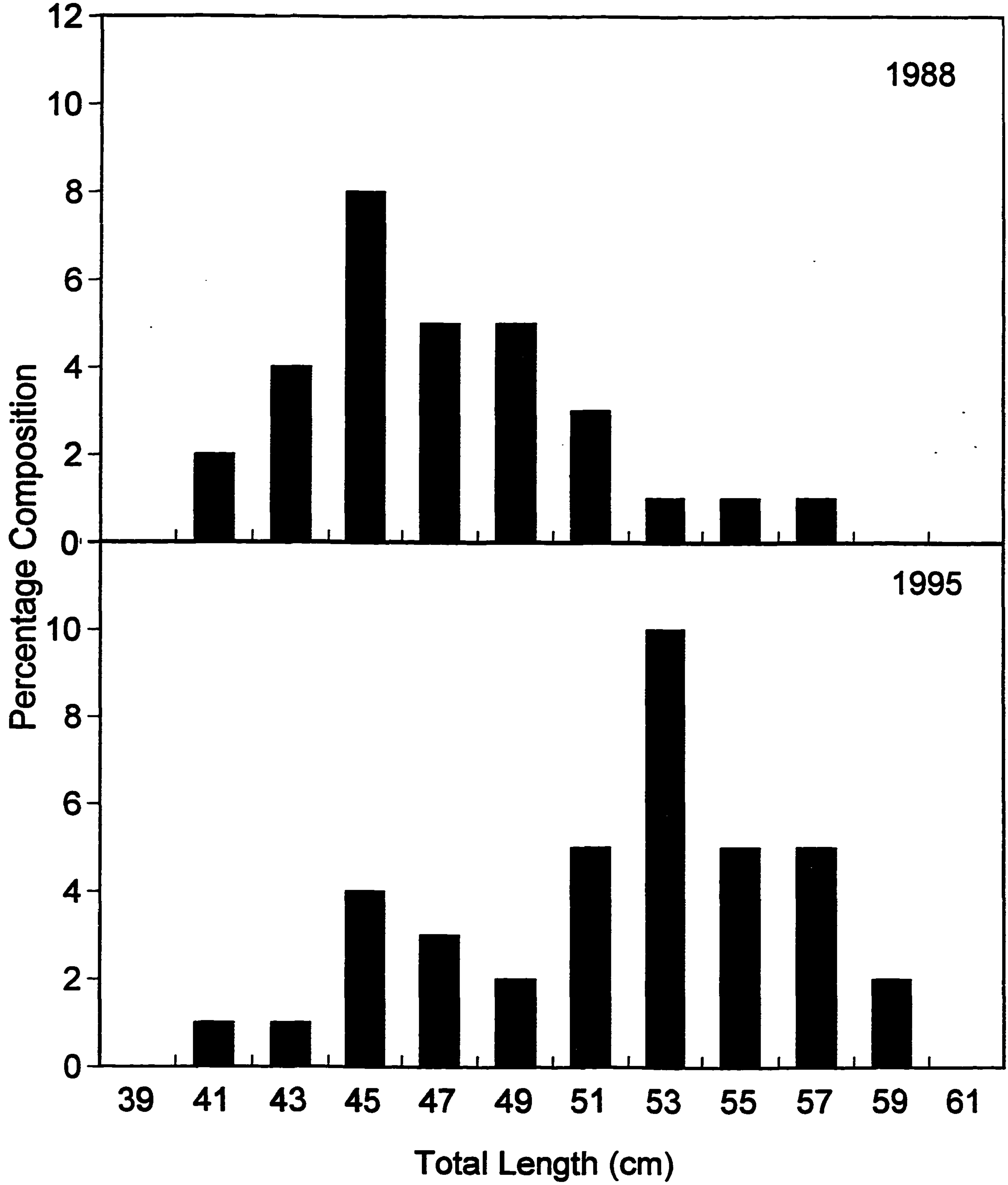

1994
1995
Percentage Composition
0
10
20
30
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Age

Figure 11. Length distribution of white suckers in Henderson Lake (N=30 in 1988 and N=42 in 1995).


1988
1995
Percentage Composition
0
2
4
6
8
10
12
39
41
43
45
47
49
51
53
55
57
59
61
Total Length (cm)

walleye decreased significantly from 1.16 in 1994 to 0.950 in 1995 (T-test, $p<0.001$, df=395). Mean condition of northern pike decreased significantly from 0.680 in 1994 to 0.530 in 1995 (T-test, $p<.001$, df=398).

Stomach Analysis

Northern pike and walleye shared similar diets. The ninespine stickleback was the item most utilized by both northern pike and walleye as seen prior to the disappearance of the species in 1983 (Fig. 12). Northern pike had a more diversified diet with five different prey items while walleye had only two. Yellow perch were the second most common species in stomach samples of both walleye and northern pike. Partial digestion of stomach contents made identification impossible for a respective 26 and 36 percent of walleye and northern pike sampled.

Weather Analysis

Between 1960 and 1995, the mean number of growing degrees above 5 degrees Celsius was 1423.1 (Fig. 13). Both 1994 and 1995 were warmer than the mean.

Population Prediction Model

Variations, A and B, estimated walleye abundance in 1995 to be 781 and 1213 walleye respectively (Fig 14). Extrapolating 20 years beyond 1984 yielded respective estimates of 3280 and 1650 walleye for variations A and B.

Figure 12. Stomach contents of walleye and northern pike in Henderson Lake during 1994 and 1995.

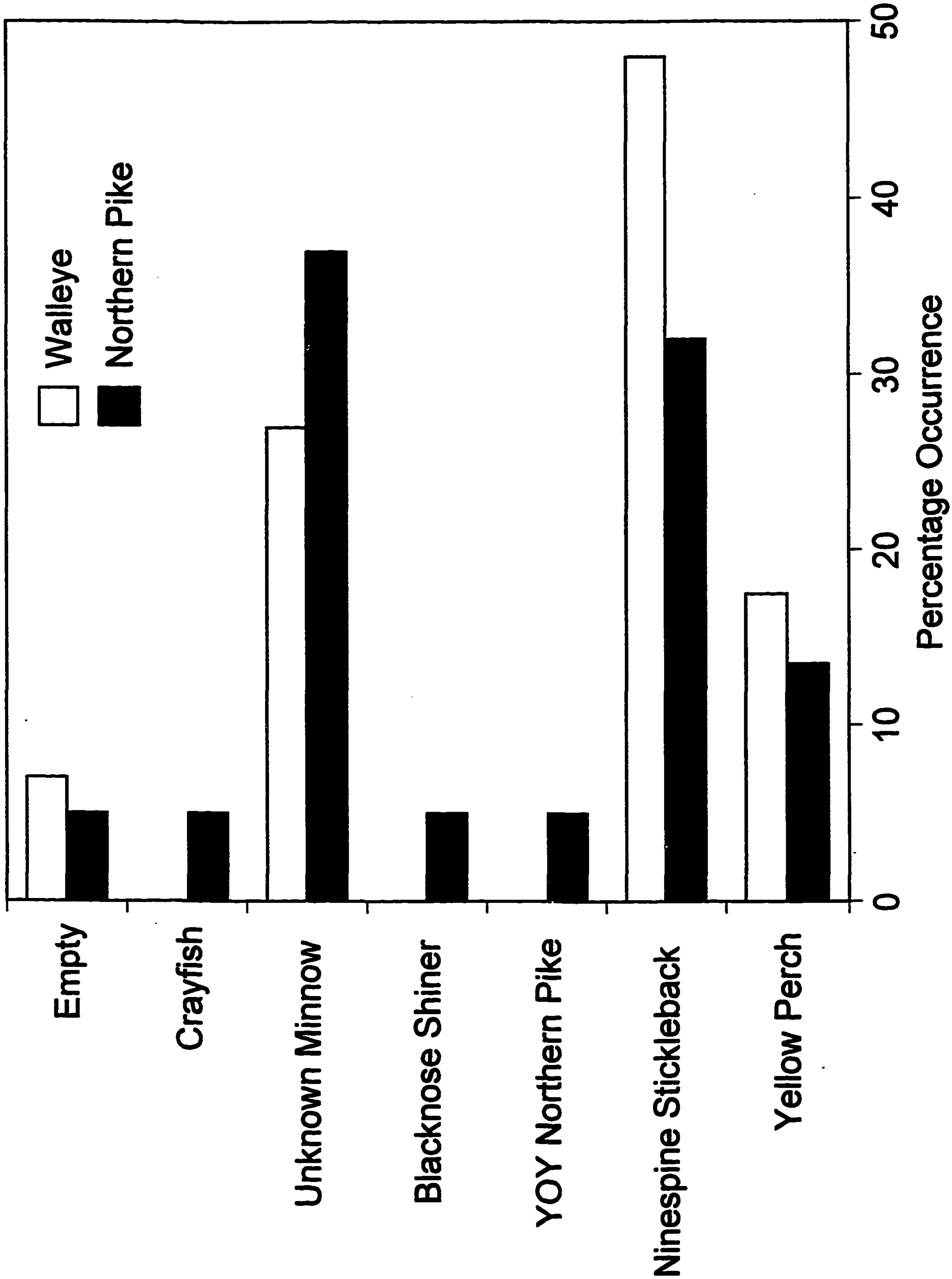
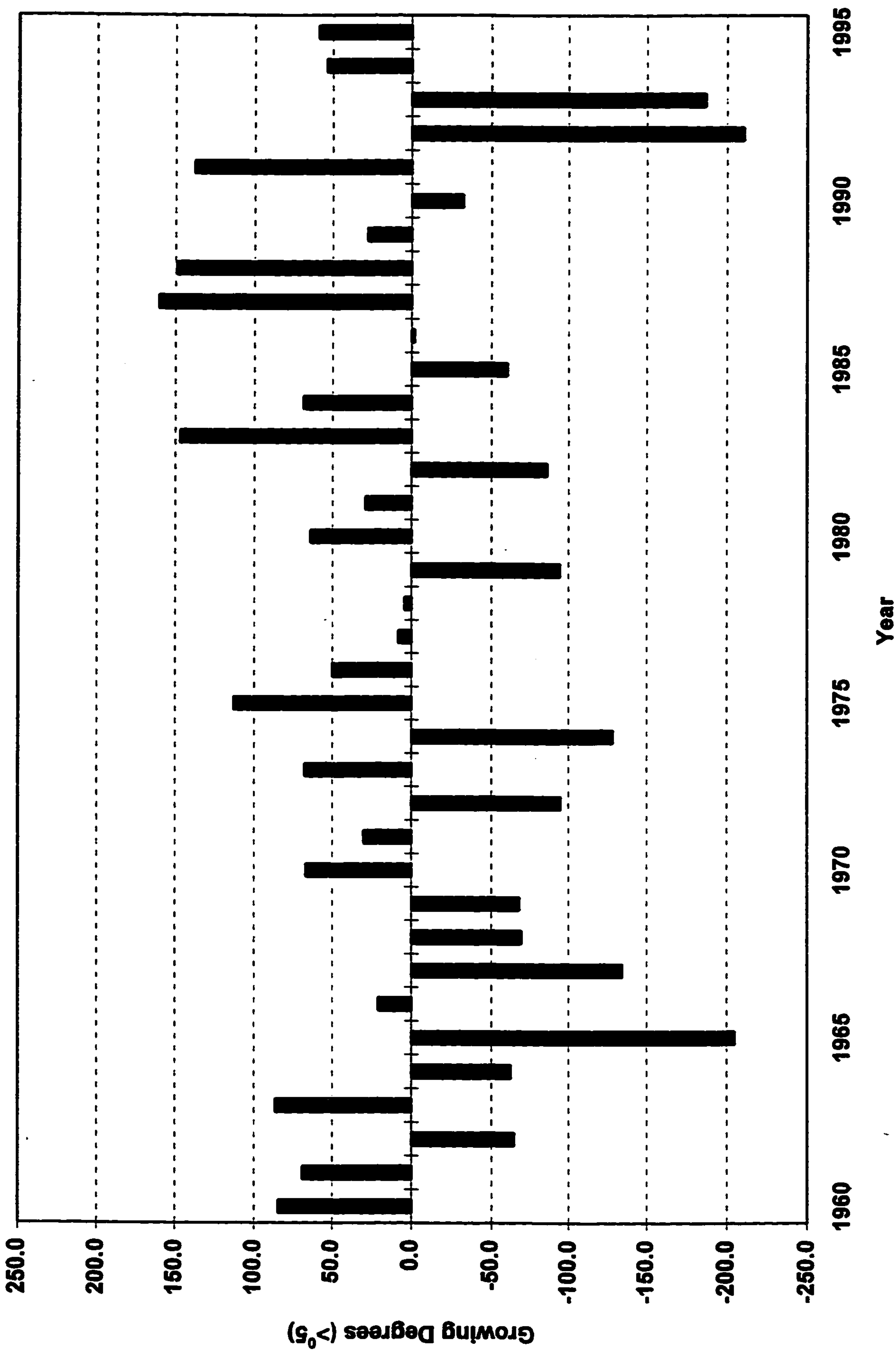
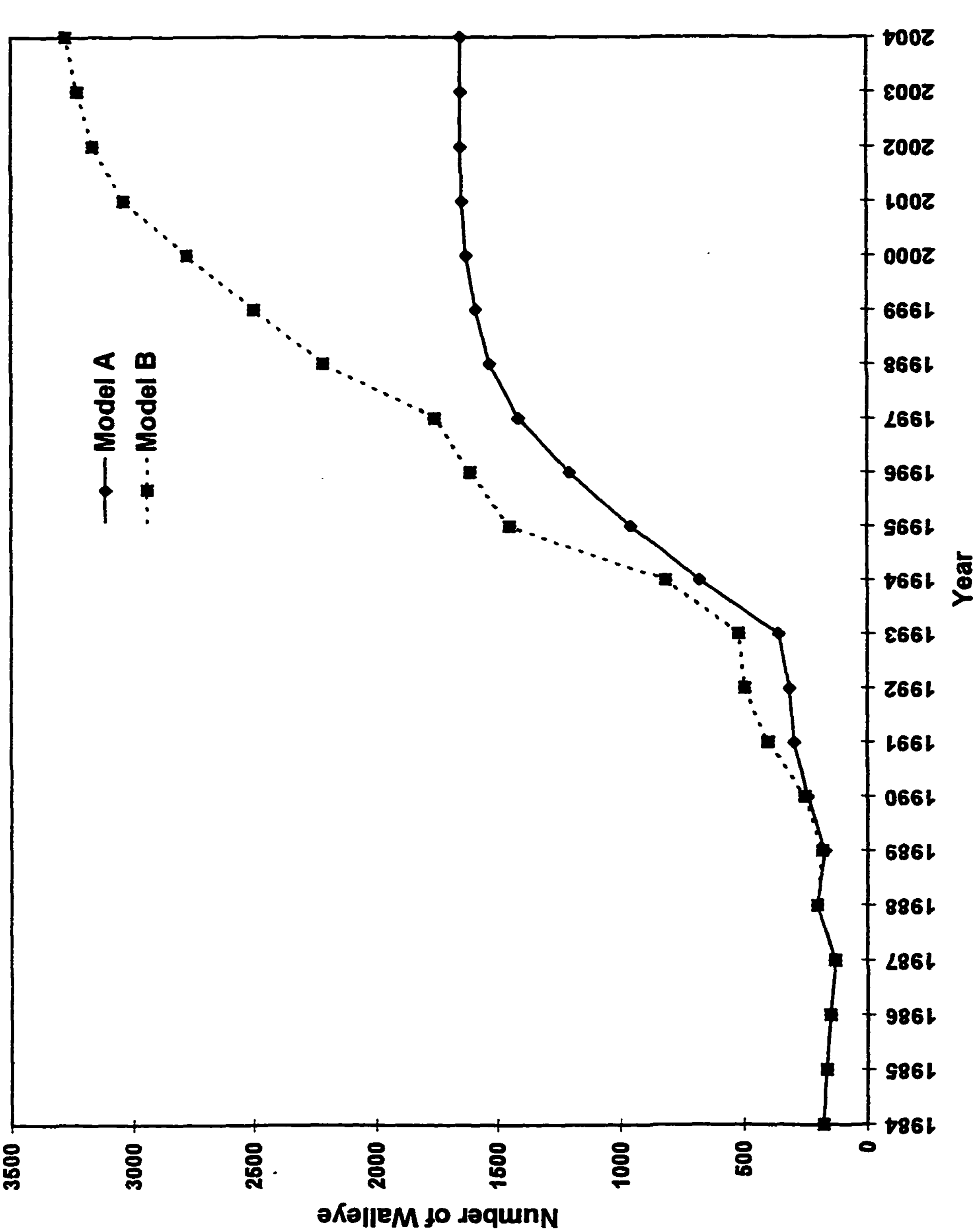

Walleye
Northern Pike
Empty
Crayfish
Unknown Minnow
Blacknose Shiner
YOY Northern Pike
Ninespine Stickleback
Yellow Perch
0
10
20
30
40
50
Percentage Occurrence

Figure 13. Deviation from mean growing degree days (1259.2) above 5^0 Celsius. Temperatures for 1971 to 1984 are from the nearby Raith weather station. A correction of $y=0.89X-8.8$ ($r^2=.98$) was used to supplement missing local temperatures with Thunder Bay records.



Growing Degrees (>05)
250.0
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
-250.0
1960
1965
1970
1975
1980
1985
1990
1995
Year

Figure 14. Predicted numbers of walleye in Henderson Lake.



Model A
Model B
Number of Walleye
0
500
1000
1500
2000
2500
3000
3500
Year
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

Discussion

Population Response

Since the population collapse in 1983, walleye had recovered sufficiently by 1994 to permit a mark and recapture population estimate (Table 2). The recovery was unexpected since previous attempts to determine abundance were unsuccessful in 1986, 1988 and 1991. By 1995 the estimated population reached approximately 25 percent of preharvest numbers.

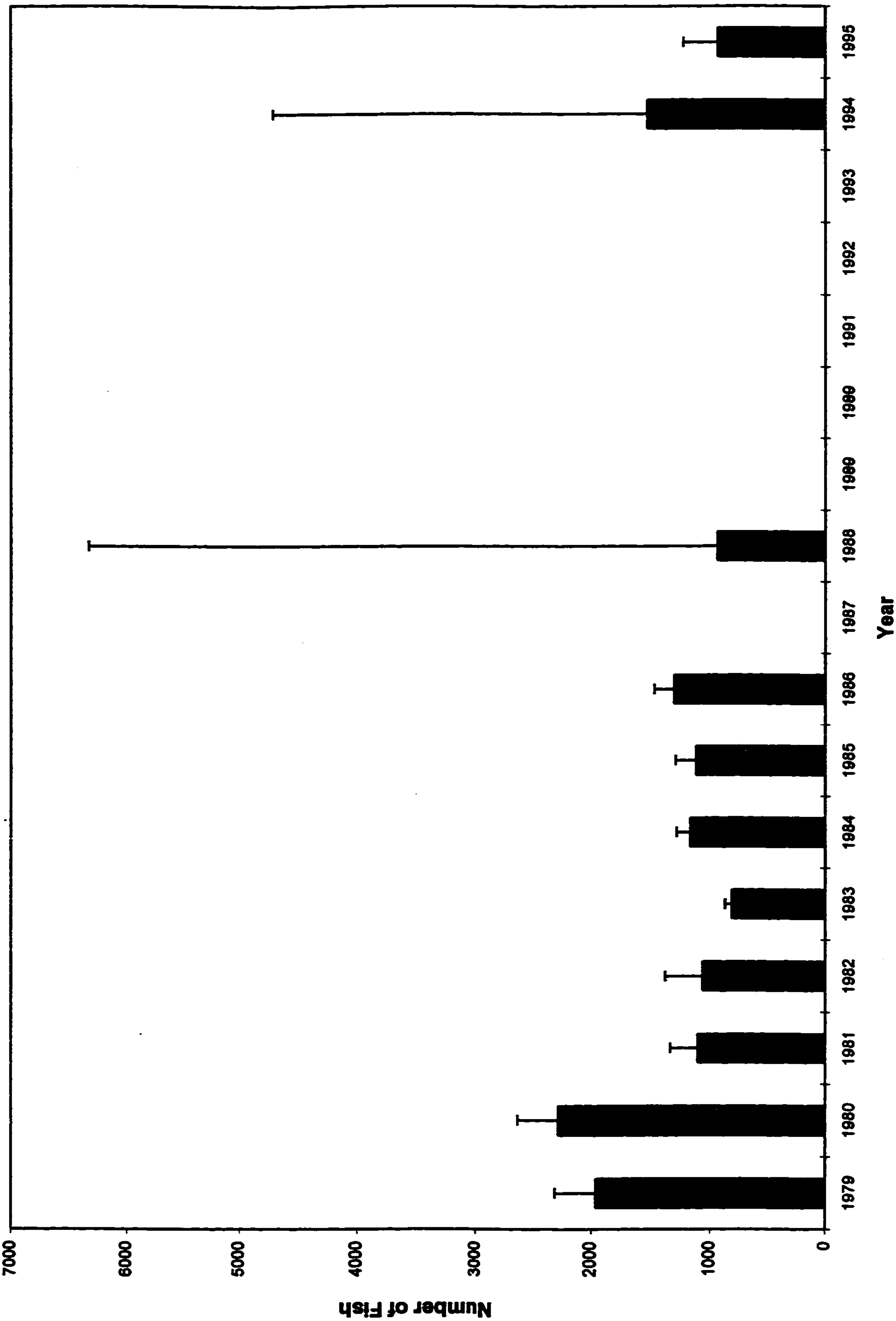
Surprisingly, northern pike numbers decreased from a pre-exploitation number of 2285 fish in 1980 to 934 fish in 1995 (Fig. 15). I expected given a large harvest of walleye, which share forage items with northern pike, that northern pike would proliferate. Northern pike density in Murphy Flowage, Wisconsin was positively correlated with forage availability (Snow 1978). Between 1980 and 1985, 1000 northern pike (2 kg/ha/year) were removed from Henderson Lake for research purposes and by incidental gillnetting for walleye. Compared to the walleye, the harvest of northern pike was less intense. Additionally, northern pike production dramatically increased following the 1980-82 walleye harvest and by 1986 their numbers appeared to be increasing (Wisenden 1988). However, in nearby Savanne Lake a similar decrease in northern pike followed a harvest of walleye (Colby and Baccante 1996). In contrast, an effort to eradicate northern pike in Heming Lake, Manitoba prompted increased reproduction resulting in this species becoming more numerous (Lawler 1960). This harvest which went from 1945 to 1958 resulted in the removal of up to 4.5 kg/ha/yr. Northern pike could not be exterminated, even by fishing in one year, the equivalent of one set of 219 817 meters of gillnet in this 259 hectare lake (Lawler 1960).

Table 2. Summary of population estimates and exploitation rates for Henderson Lake walleye from 1979 to 1995. (Modified from Reid 1985); Reid and Momot 1985 and Wisenden 1988.

Year	S-E Population Estimate	Peterson Population Estimate	Virtual Population estimate[1]	Number Removed	Removed[2] (%)	Exploitation[3] Rate	CUE (fish/hour)
1979	1336	-	-	-	-	-	0.3924
1980	1588	2707	3608	1332	36.9	49	0.4405
1981	1183	2163	2276	1115	49	52	0.3188
1982	945	1194	1161	779	67.1	66	0.0943
1983	375	312	382	106	27.7	-	0.0691
1984	152	169	276	43	15.6	-	0.0684
1985	129	-	233	0	-	-	0.0119
1986	102	-	-	0	-	-	0.0245
1994	772	-	-	-	-	-	0.0610
1995	871	-	-	-	-	-	0.0664
Total				3375	93.5[4]		

[1]Virtual population estimate =total number removed each year + 1983 population estimate
[2]Number removed ÷ Virtual population estimate
[3]Percentage of clipped subsequently removed
[4]Total removed ÷ total virtual population = 3375 ÷ 3608

Figure 15. Schumacher-Eschmeyer population estimates for northern pike from 1979-1986, 1988, 1994 and 1995 in Henderson Lake, Ontario. Error bars indicate 95% confidence limits. Data from 1979 to 1981, Nunan (1982); 1982 to 1984 , Reid (1985); and 1985 to 1986, Wisenden (1988).



Number of Fish
0
1000
2000
3000
4000
5000
6000
7000
Year
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

The normal carrying capacity in Henderson Lake may be considerably lower than the 2285 fish recorded in 1980. The years 1977-79 were average or cooler than the mean (Fig 13) which favors northern pike (Diana 1987) and may have resulted in several exceptional year-classes. Possibly, Henderson Lake supports a northern pike population closer to 1000+ fish as recorded for the last 15 years.

There was considerable difficulty in attempting to estimate the size of walleye populations in Henderson Lake. Reid and Momot (1985) hypothesized that social dominance at spawning time by older, sexually mature fish excluded younger fish from the spawning shoal. Hence at high density only a portion of the population is susceptible to nearshore mark and recapture sampling. The removal of older, dominant walleye by the pulse fishery allowed the younger walleye to then utilize the spawning areas. Spring netting targets older spawning fish but would not include the younger and subdominant walleye. Therefore the population estimates derived from the mark and recapture of only a portion of the population cannot provide a true estimate of the total population.

As a result of the underestimates, an unintentional overharvest of walleye occurred removing 90 percent of the population. Consistently low Schumacher-Eschmeyer estimates during the experimental harvests failed to accurately indicate the effects of the previous years removal. Fortuitously, the removal was so intense that it was possible to determine more precisely the before harvest density. A 'virtual' estimate of walleye abundance (spring 1980), consisted of accumulating the number of fish removed (when recruitment was minimal) and adding the remaining fish estimated in 1983 (Table 2). This added accuracy in hindsight and suggests the Schumacher-Eschmeyer method underestimated the actual walleye population for this study by

50 percent.

Catch per unit effort (CUE) for the six foot trapnets was a better indicator of trends in walleye abundance than the Schumacher-Eschmeyer estimates during the harvest phase of the study (Fig. 16). The social dominance hypothesized by Reid and Momot (1985) possibly resulted in lower population estimates from multiple recaptures. After spawning, the walleye redistribute throughout the lake so a more representative sample is caught and may explain the more accurate Petersen estimates which were conducted in the fall (Fig. 16). The Petersen estimate was not used in 1994-95 for three reasons; first it would have involved gillnetting an already depleted stock, secondly the Schumacher-Eschmeyer was shown to accurately estimate walleye numbers at lower population densities (Reid and Momot 1985) and thirdly the trends in abundance shown by the trapnet CUE's and two spring estimates were in agreement.

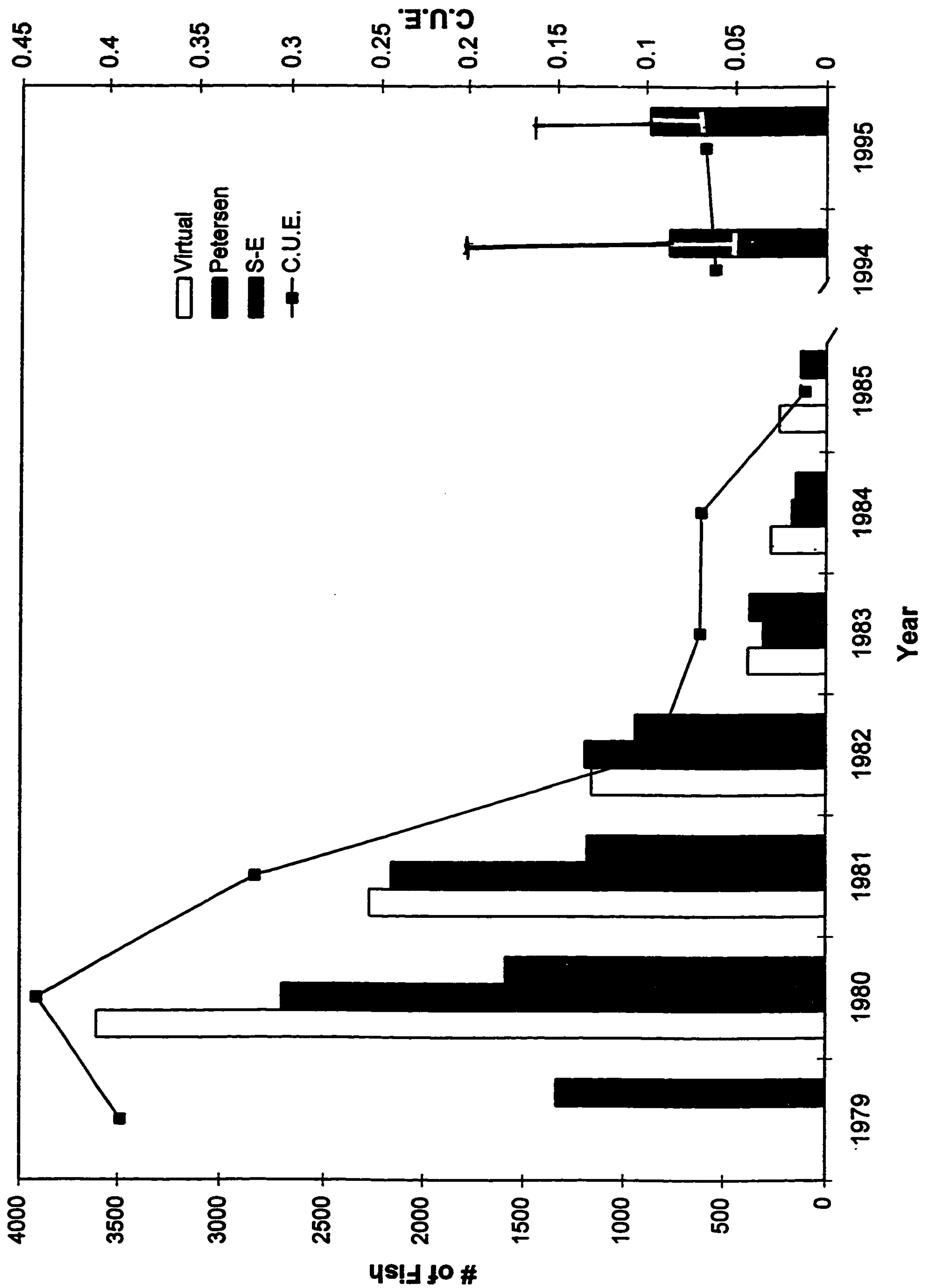
The spring Schnabel estimate did not exceed the confidence limits of Schumacher-Eschmeyer estimates for either walleye or northern pike for 1994 or 1995 (Fig. 3). The Schumacher-Eschmeyer estimate was likely more accurate for walleye abundance since the Schnabel estimate decreased in 1995 with two strong year-classes entering the fishery (Fig. 8).

I was unsuccessful at estimating white sucker numbers. Previous researchers had experienced similar difficulty in determining white sucker abundance (Reid 1985, Colby and Baccante 1996).

Growth and Condition

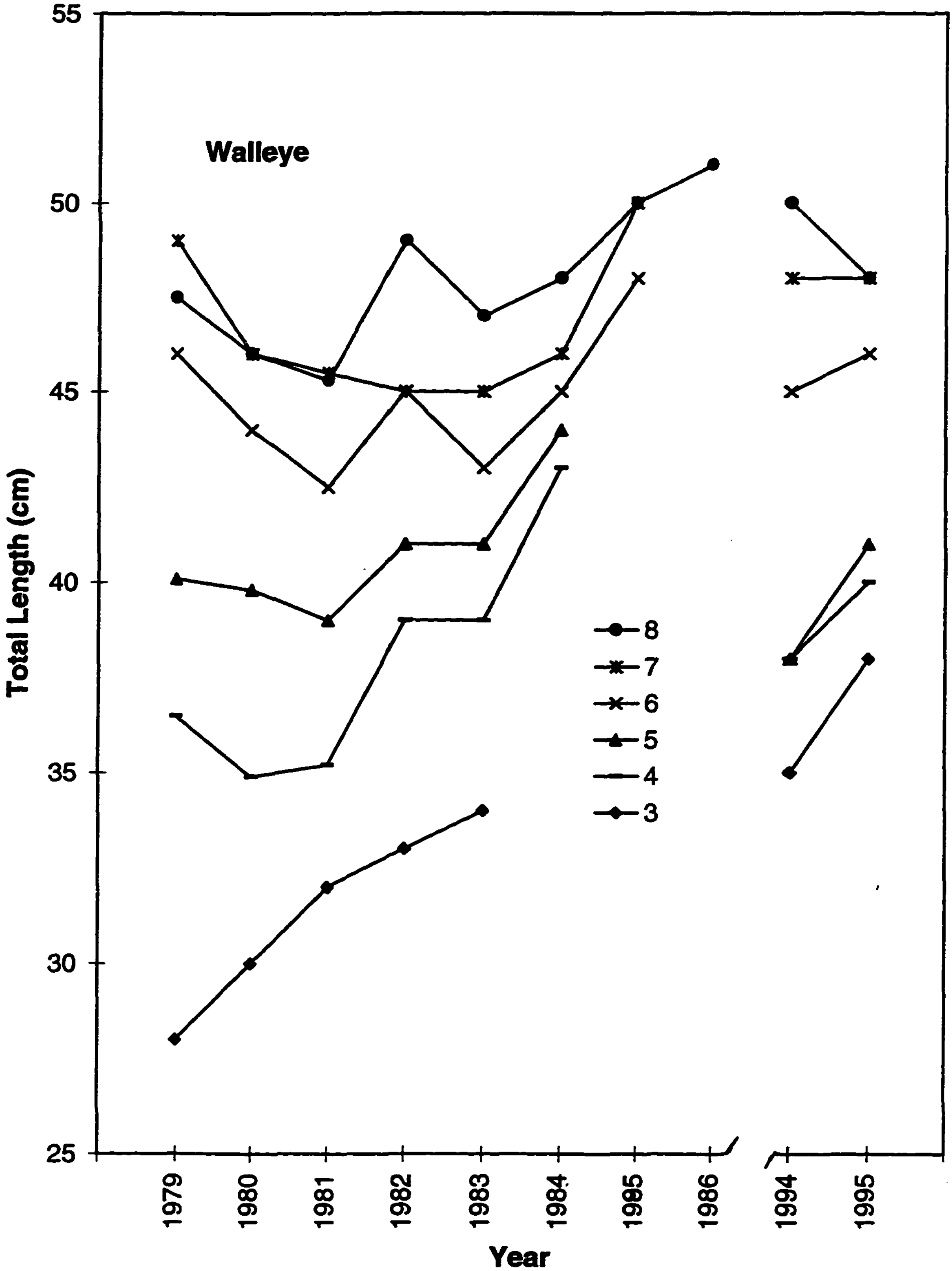
Average length of walleye ages three to eight responded to the removal and recovery of walleye in Henderson Lake (Fig. 17, Appendix I, Table 1). The average lengths of walleye ages three to eight were greater in 1986 than 1982. In 1994 average length at age was less than 1986, likely in response to the increase of the walleye population and two cool summers (Fig. 13).

Figure 16. The catch per unit effort of six foot trapnets compared to virtual, Petersen and Schumacher-Eschmeyer (S-E) population estimates of walleye in Henderson Lake.



# of Fish
0
500
1000
1500
2000
2500
3000
3500
4000
C.U.E.
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
Virtual
Petersen
S-E
C.U.E.
1979
1980
1981
1982
1983
1984
1985
1994
1995
Year

Figure 17. Mean length at age for walleye in Henderson Lake. Data from 1979 to 1981, Nunan (1982); 1982 to 1984 , Reid (1985); and 1985 to 1986, Wisenden (1988).


Walleye
Total Length (cm)
55
50
45
40
35
30
25
8
7
6
5
4
3
1979
1980
1981
1982
1983
1984
1985
1986
1994
1995
Year

Walleye growth has been positively correlated to growing degree days for fish ages 3 to 5 in nearby Lac de Milles Lacs (M. Freutel, O.M.N.R. Unit Biologist). Except for the large 8 year olds the average length at age increased for walleye during the warm summers of 1994-95.

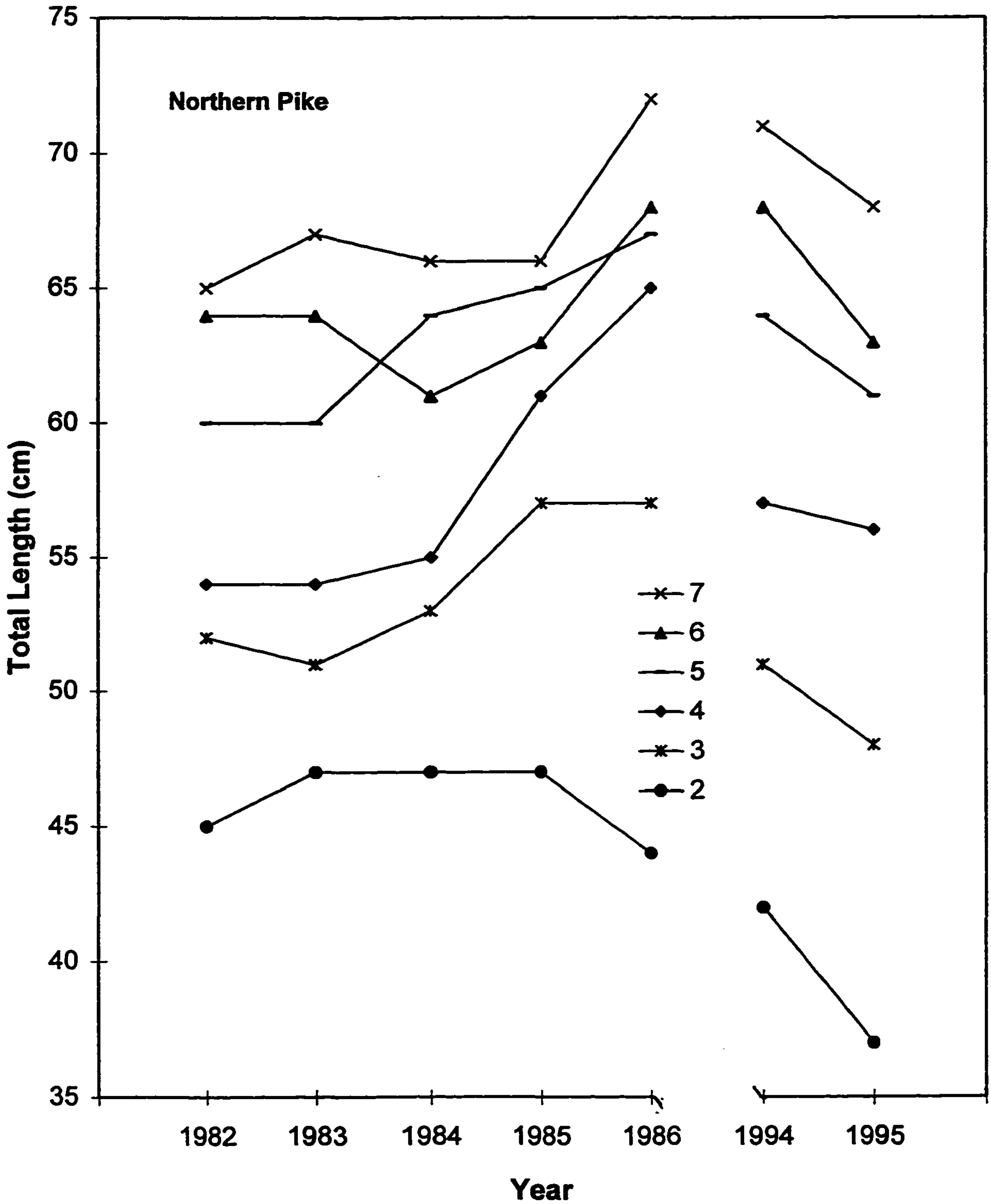
Significant greater growth increments backcalculated from 1994 walleye scales were associated with positive environmental effects during the years 1987 and 1988. Both 1987 and 1988 were warmer than the 35 year growing degree day average (> 5^0C) mean (Fig. 13). Warmer years favor stronger year classes (Colby and Lehtonen 1994).

Following the cessation of the walleye harvest, northern pike average length for ages three to eight, also increased (Fig. 18, Appendix 1, Table 2). However, between 1994 and 1995 the average length at age of northern pike declined along with their abundance.

Northern pike backcalculated growth (from 1995 scales) was significantly greater in 1990 (t test, $P<0.01$ df=56), a year that was cooler than the mean (growing degrees >5^0C) and would favor northern pike growth (Diana 1987).

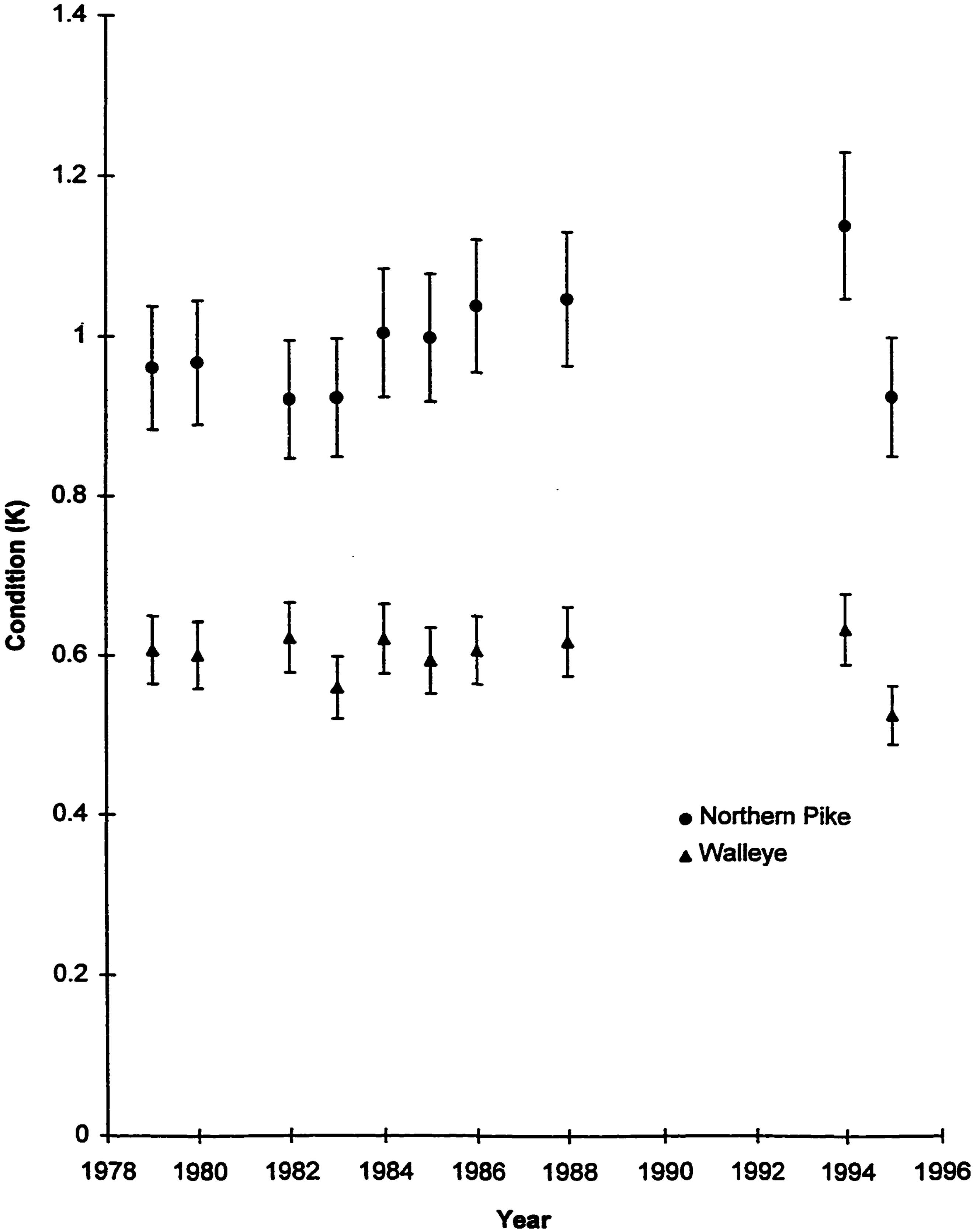
Mean condition of walleye and northern pike varied little throughout the study period (Fig. 19). Henderson Lake was compared to nearby Savanne Lake to minimize climatic influences on harvest and recovery responses. The two lakes contain similar fish species, however Savanne has cisco (*Coregonus artedii*) as a larger and cooler water forage item (Colby *et. al.* 1987). The condition of the less dense walleye population in Henderson Lake, was significantly greater in 1994 (μ=1.16, t test, $P<0.001$, pooled df=251) than that of Savanne Lake walleye (μ=1.01). However, in 1995 the condition of Henderson Lake walleye (μ=0.950, t test, $p<0.001$, pooled df=250) was significantly less than that of Savanne Lake walleye (μ=1.11). This suggests that they may be stressed, such as decreased forage or increased competition from year-classes of

Figure 18. Mean length at age for northern pike in Henderson Lake. Data from 1979 to 1981, Nunan (1982); 1982 to 1984 , Reid (1985); and 1985 to 1986, Wisenden (1988).



Northern Pike
Total Length (cm)
Year
75
70
65
60
55
50
45
40
35
1982
1983
1984
1985
1986
1994
1995
7
6
5
4
3
2

Figure 19. Average condition factor ($k = weight/Length^3 x 10^6$) for walleye and northern pike in Henderson Lake. Data from 1979 to 1981, Nunan (1982); 1982 to 1984, Reid (1985); and 1985 to 1986, Wisenden (1988). Error bars represent 95 percent confidence limits.



1.4
1.2
1
0.8
0.6
0.4
0.2
0
Condition (K)
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Year
Northern Pike
Walleye

younger fish not yet recruited to the gear. Since condition is a cubic function of weight divided by length, the increase of younger fish recorded in the length distributions, with less volume to length, also would lower the mean condition values.

The mean condition of Henderson Lake northern pike (μ=0.670) as compared to that of nearby Savanne Lake (μ=0.670) was not significantly different in 1994 (t test, $p>0.05$, df=264). However, northern pike mean condition in 1995 was significantly lower for Henderson Lake (μ=0.540) than Savanne Lake (μ=0.710, t test, $p<0.001$, pooled df=273). During the same period, the mean age of the Henderson Lake northern pike population varied little from 5.5 to 5.4 years.

High water temperatures can also effect condition of northern pike. Northern pike often use the metalimnion of well-oxygenated lakes as a refuge from low oxygen and high temperatures (Diana 1987). Because Henderson Lake is too shallow to stratify thermally, there is no cool water summer refugia. In warm years this could reduce ingestion and increase metabolic costs resulting in reduced or negative growth (Diana 1987). Northern pike in an Ohio impoundment lost weight during the summer months and sought cooler water (Headrick and Carline 1994). Casselman (1978b) identified the optimum temperature for growth at 19-23 ^{0}C. The summers of 1994 and 1995 were warmer than the average (Fig. 13) with water temperatures approaching 26 ^{0}C (Appendices 3 and 4). Northern pike likely experienced increased metabolic costs with more energy needed for respiration, thus limiting growth (Diana 1987, Raat 1988). In addition, cooler temperatures would retard the growth of certain forage so that the forage would not become too large for predation.

Algal blooms noted during the summer of 1995 reduced water clarity in Henderson Lake. A comparison of walleye and northern pike populations in central Canada correlated summer condition of northern pike to secchi depths (Craig and Babaluk 1989). Turbidity may reduce food consumption and thus growth for this visual predator.

The condition of northern pike was a poor indicator of the exploitation that occurred (1980-1982) in Henderson Lake (Reid and Momot 1985) and was possibly confounded by differences in annual temperatures. The variation in condition between 1994 and 1995 was likely due to the time of sampling. In 1994 the fish were collected during the late spring to early summer when they were beginning to feed and grow. The 1995 netting began earlier during spawning, a time when weight can vary considerably. In addition, increased gonadal production (due to earlier maturation) may mask any gains in weight due to increased food availability brought about by a reduction in density of predators (Diana 1987).

Age and Length Relationships

The bimodal length and age distributions of walleye in 1995 (Fig. 20 and 21) resembled those of the undisturbed population (Nunan 1982). Older, slower growing fish formed the smaller peak (ages 7 to 14, total lengths 49 centimeters and longer) while younger fish formed the larger peak (ages 2 to 6, total lengths less than 49 centimeters). The 1980 to 1982 harvests targeted older, and larger walleye resulting in unimodal length and age distributions (Reid 1985). The unimodal distributions continued from 1983 to 1986 when recruitment to the trapnets was negligible.

In 1994, four year-classes (1987 through 1990) of walleye ages 4 to 7 were strongly represented in Henderson Lake forming the larger peak of the bimodal curve (Fig. 9). The 1985

Figure 20. Total length distributions of walleye in Henderson Lake. Data from 1979 to 1981, Nunan (1982); 1982 to 1984 , Reid (1985); and 1985 to 1986, Wisenden (1988).

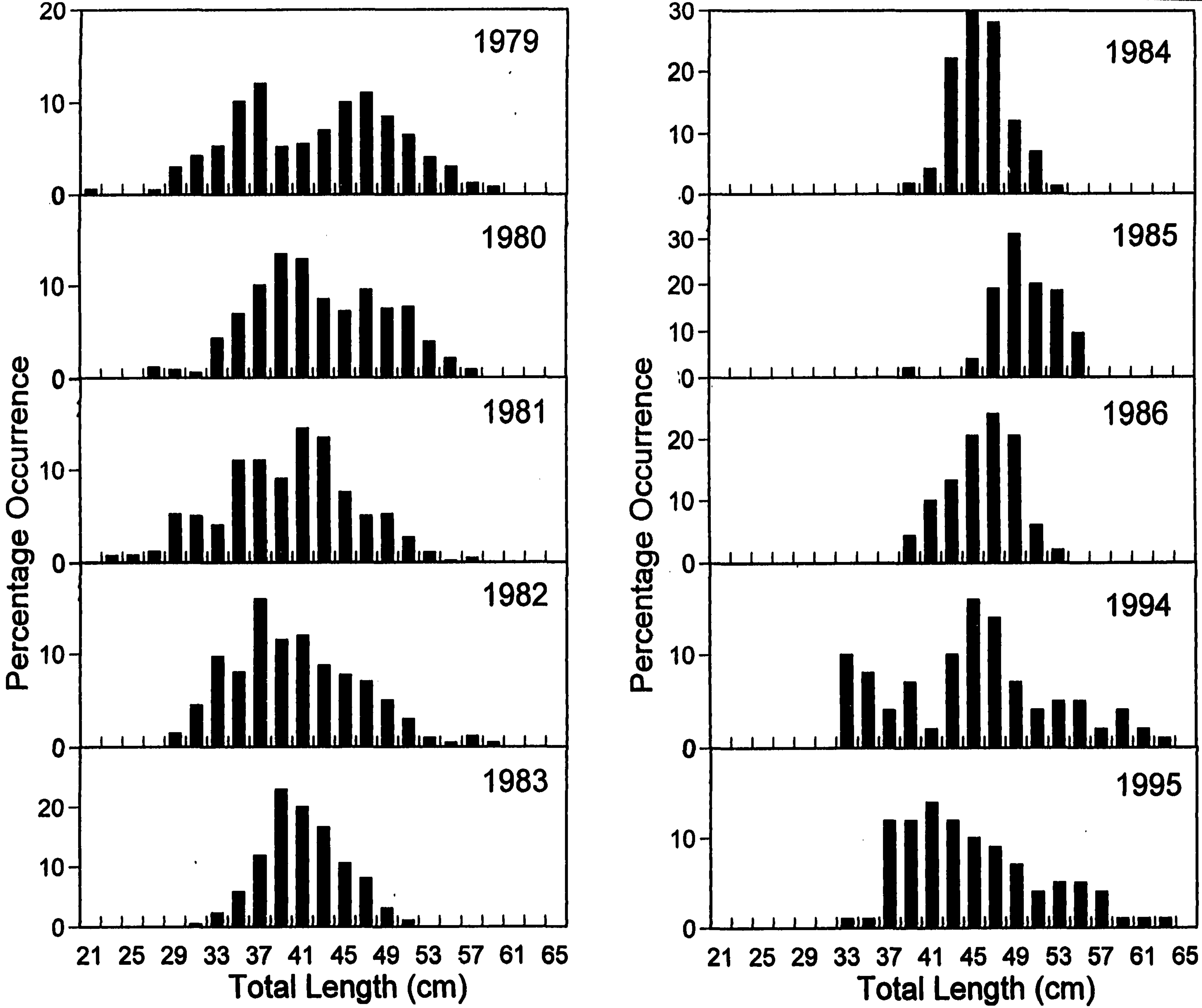
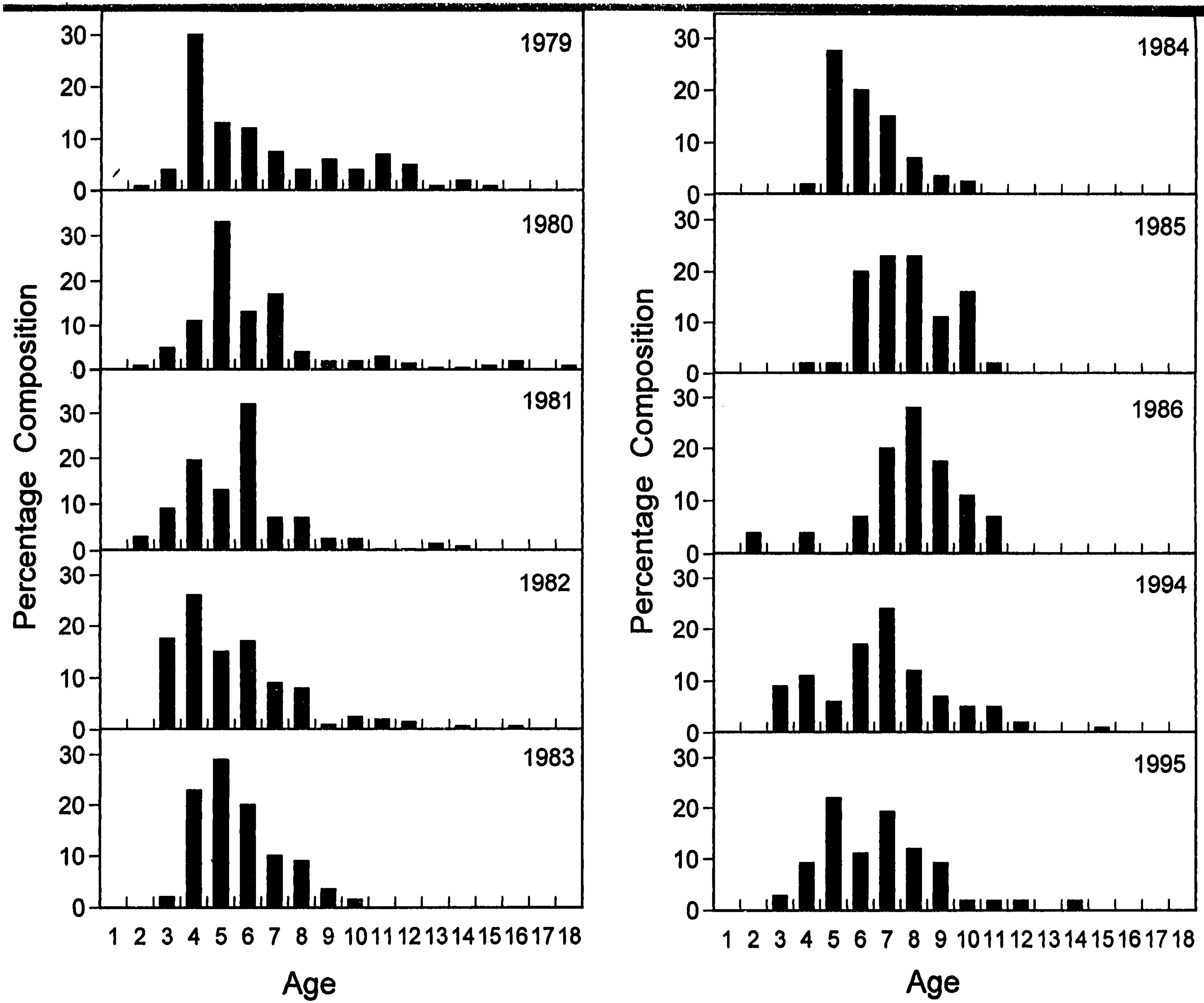

1979
1980
1981
1982
1983
1984
1985
1986
1994
1995
Percentage Occurrence
Total Length (cm)
21 25 29 33 37 41 45 49 53 57 61 65

Figure 21. Age distributions of walleye in Henderson Lake. Data from 1979 to 1981, Nunan (1982); 1982 to 1984 , Reid (1985); and 1985 to 1986, Wisenden (1988).


Percentage Composition
1979
1980
1981
1982
1983
1984
1985
1986
1994
1995
0
10
20
30
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Age

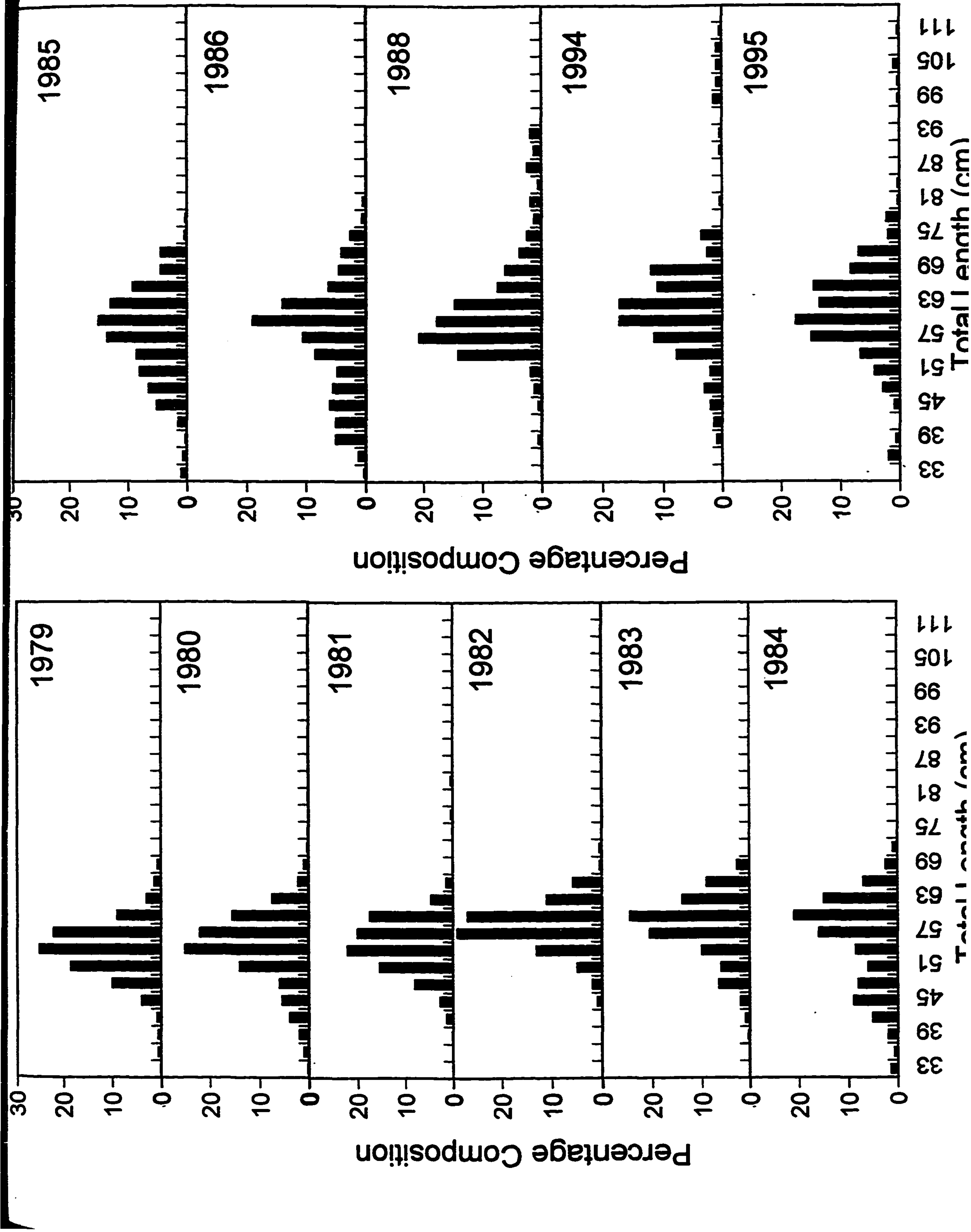
and 1986 year-classes which were recorded as abundant YOY (Reid and Momot 1985, Wisenden 1988), were still present as 8 and 9 year olds in the 1994 catch. Those two faster growing year-classes likely matured earlier and may have been instrumental in the resurgence of the population. The prominent 1987 and 1988 year-classes were produced during two warm summers which favor walleye YOY production (Colby and Lehtonen 1994, Ritchie and Colby 1988). The trimodal shape of 1994 walleye length distributions was partially obscured in 1995 by the continued recruitment of the 1987 and 1988 year-classes to the gear (Fig. 7).

Strong walleye year-classes in 1987 and 1988 were also observed by other investigators. Nearby Savanne Lake produced strong 1987 and 1988 year-classes (P. Colby, O.M.N.R. Scientist pers. comm. 1996). Strong year-classes were reported in 1987 for Lake of the Woods (T. Mosindy, O.M.N.R. Unit Biologist, Lake of the Woods Fisheries Assessment Unit, 1996) and in 1988 for Whitefish Lake, Lac des Milles Lacs and Pekagoning Lake (M. Freutel, O.M.N.R. Unit Biologist, Quetico-Mille Lacs Unit, Fisheries Assessment Unit, 1996). The 1991 year-class, which was not yet fully recruited to the gear in Henderson Lake, was reported as a strong year-class in Whitefish Lake, Sandstone Lake, Lac des Milles Lacs,and Lake of the Woods.

A study of arctic char (*Salvelinus alpinus*) in Keyhole Lake, Victoria Island N.W.T. showed a similar trend of length to age distributions following an intense disturbance (Johnson 1994a). Bimodal length and age distributions were present before the harvest and after the recovery. The distributions became unimodal during the harvest and recovery similar to Henderson Lake walleye.

Northern pike length distributions in 1994 and 1995 resembled the unperturbed population except there was an increase of larger fish (Fig. 22, Nunan 1982). This species reaches greater

Figure 22. Total length distributions of northern pike in Henderson Lake. Data from 1979 to 1981, Nunan (1982); 1982 to 1984 , Reid (1985); and 1985 to 1986, Wisenden (1988).

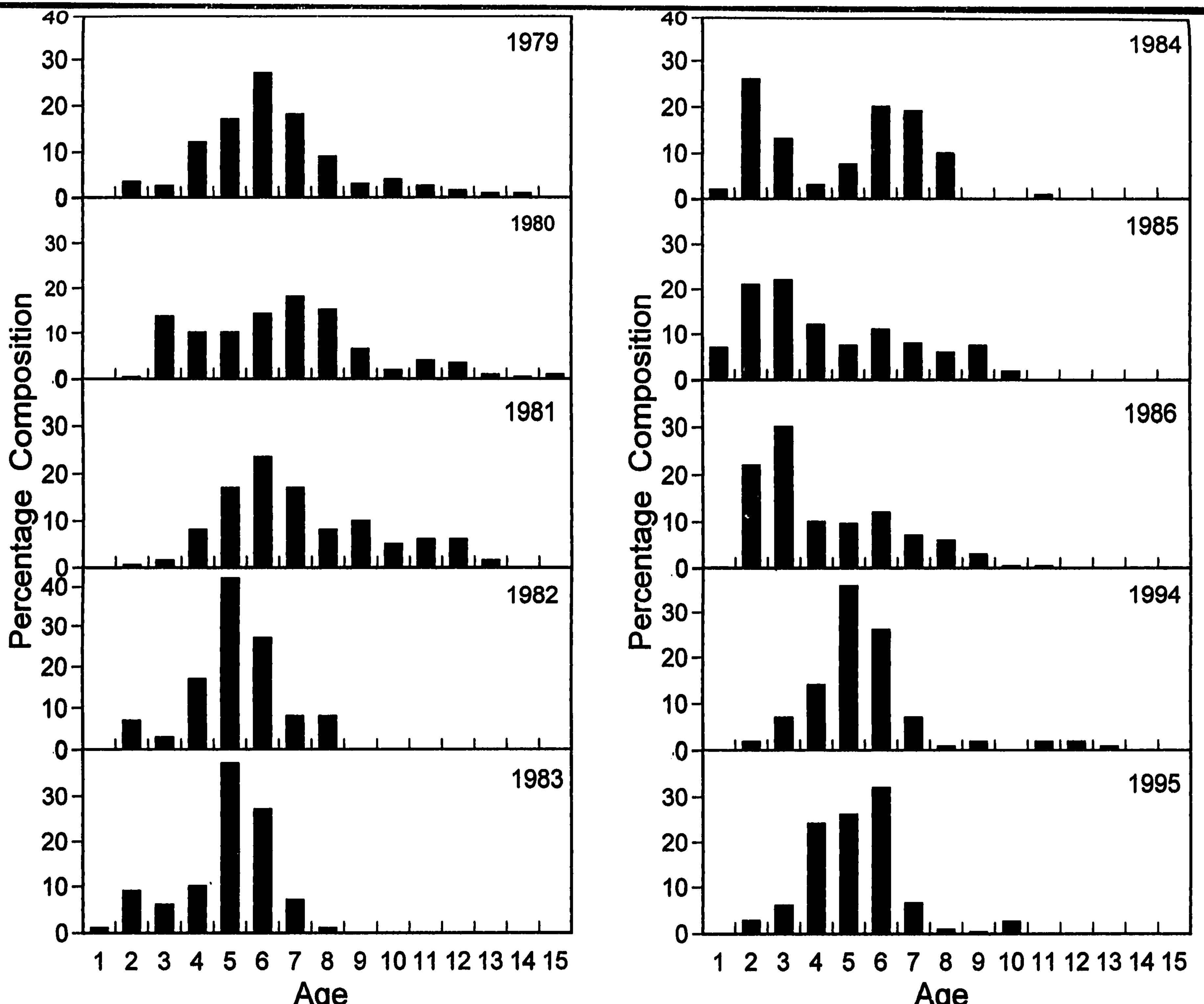

1979
1980
1981
1982
1983
1984
1985
1986
1988
1994
1995
Percentage Composition
Percentage Composition
33
39
45
51
57
63
69
75
81
87
93
99
105
111

lengths than walleye in Henderson Lake forming unimodal distributions with older, longer fish skewed to the right. The majority of the fish were between 40 and 75 centimeters total length with a few fish larger than 90 centimeters. Northern pike greater than 90 centimeters were more numerous in 1994 and 1995 than in previous years. Prior to the harvest, benthic organisms were a large component in northern pike stomach samples (Nunan 1982). During and following the harvest northern pike became piscivorus on ninespine sticklebacks and yellow perch. In addition, I noted when processing larger northern pike that they did not recover as well as smaller fish, especially in warmer water. The cessation of intensive netting may have allowed these sensitive fish to grow beyond sizes seen during the period when Henderson Lake was heavily netted.

Northern pike age distribution was similar to walleye with older fish disappearing from the population during the harvest (Fig 23). By 1995 age distributions were similar to those of the unperturbed population.

In 1994 and 1995 mean ages of walleye were comparable to the preharvest numbers. The following are mean ages (μ) $\pm$ standard deviation (S.D.) for sexes combined of walleye and northern pike in Henderson Lake from 1979 to 1995:

Figure 23. Age distributions of northern pike in Henderson Lake. Data from 1979 to 1981, Nunan (1982); 1982 to 1984 , Reid (1985); and 1985 to 1986, Wisenden (1988).



Percentage Composition
Age
1979
1980
1981
1982
1983
1984
1985
1986
1994
1995

Year	Walleye $\mu \pm$	S.D.	Northern Pike $\mu \pm$	S.D.
1979	6.7	3.0	6.4	2.1
1980	6.6	2.8	6.7	2.6
1981	5.7	2.3	7.1	2.3
1982	5.9	2.7	5.0	1.2
1983	5.7	1.6	4.9	1.4
1984	6.6	1.6	4.8	2.3
1985	7.7	1.5	4.4	2.5
1986	7.9	1.9	4.3	2.1
1994	6.7	2.1	5.5	1.7
1995	6.5	2.5	5.4	1.5

During the 1980 to 1982 harvest period, the mean ages of walleye decreased with the removal of older fish from the population. This is a characteristic of overfishing (Colby *et. al.* 1994). Mean ages increased from 1983 to 1986 during the period of poor recruitment. I expected the mean age of walleye in 1994 and 1995 to be lower than the preharvest value as younger fish recruited to the population. However, the mean age was similar to preharvest values because the proportion of new recruits was not sufficient to effect the mean age of a growing and aging population.

The mean age of northern pike in 1994 and 1995 was considerably less than that of the preharvest values, due to a higher proportion of younger recruits in a declining population as indicated by age distributions.

Community Changes

The decline and disappearance of the ninespine stickleback in 1982 after predator reduction remains unexplained (Table 3). Ritchie (1984) found stomach samples of yellow perch $\geq$ 91 mm total length contained up to 79% ninespine sticklebacks and a large year-class of yellow perch were produced in 1981. This large year-class, may have been sufficient to collapse the ninespine

Table 3. Presence (+) or absence of fishes captured in seine hauls in Henderson Lake (1979-1995).

Year	Yellow Perch	Blacknose Shiner	Ninespine Stickleback	Mimic Shiner	Burbot[1] (YOY)	Iowa Darter	White Sucker[1]	Northern Pike[1]	Walleye[1] (YOY)	Comments/Authority
1979	+	+	+	+	+	+	+	+	-	Nunan 1982
1980	+	+	+	+	+	+	+	+	-	Nunan 1982
1981	+	+	+	+	+	+	+	+	-	Severe reduction in Sticklebacks numbers/Nunan 1982 and Ritchie 1988
1982	+	+	-	+	+	+	+	+	-	Sticklebacks abscent from seine hauls/Reid 1985 and Ritchie1988
1983	+	+	-	+	+	+	+	+	-	Ritchie 1988
1984	+	+	-	+	+	+	+	+	-	Wisenden 1988
1985	+	+	-	+	+	+	+	+	+	First year yoy walleye caught/Wisenden 1988
1986	+	+	-	+	+	+	+	+	+	Yoy walleye abundant/Wisenden 1988
1994	+	+	+	+	+	+	+	+	-	Sticklebacks once again abundant in seine hauls, especially on cloudy days and after dark
1995	+	+	+	+	+	+	+	+	-	Sticklebacks and mimic shiners especially abundant on cloudy days and after dark

stickleback population. Because the ninespine stickleback has a low fecundity with females laying 20 to 30 eggs (Scott and Crossman 1973) their production may not have been sufficient to overcome yellow perch predation.

Walleye YOY were only caught in the summers of 1985 and 1986 (Wisenden 1988). This is surprising since the lake was seined and netted intensively during various times of the day and night prior to and in subsequent years (Nunan 1982, Ritchie 1984). Possible explanations for the phenomenon are: repression from a strong 1979 year-class of walleye (Nunan 1982) or perhaps poor spawning conditions.

Derback (1947) observed a cessation of spawning in Heming Lake in northern Manitoba with an onset of cold weather. The walleye left the river and did not return resulting in a poor year-class. However, in this study the springs of 1994 and 1995 were not unusually cool and mature fish were reported on the spawning shoals. Recruitment in Henderson Lake may be limited but age distributions indicate that it is continuous. My assumption is that the YOY must reside in an area of the lake which has not been netted or where capture with seines was not feasible. Recruitment may have been so negligible that YOY were undetected.

Creel Survey

Walleye angling in Henderson Lake compared favorably to other lightly fished boreal lakes having <5 rod/hours effort (Appendix 2, M. Freutel, O.M.N.R. Unit Biologist). The mean 1994-95 walleye CUE (0.82 fish per hectare), was above the 95 percent confidence limits for the mean (0.536 fish per hour, S.D. $\pm$0.12) for all 35 lakes.

The Henderson Lake walleye angling during the day was most successful near the surface. The high success rate in Henderson Lake may reflect greater vulnerability of fish not having been angled since 1986. The increase in catch per unit effort from 0.66 in 1994 to 0.99 in 1995 may reflect increased abundance and an improved understanding of their distribution and behavior. In contrast, angling catch per unit effort increased for northern pike from 1994 (1.72) to 1995 (2.85) while abundance declined. Again the increase in CUE may be due to an improved understanding of the lake and fish behavior or reflects a decline of preferred prey.

The high angling CUE was disconcerting as this is an index widely used for management decisions. Populations may become more vulnerable to angling as remaining fish become more localized in favorable habitats (Korver *et. al.* 1996). When anglers encounter localized distributions of fish they tend to stay with them and the resultant CUE may reflect local area densities rather than entire lake values (Baccante 1995, Korver *et. al.* 1996), especially among experienced anglers. The angling CUE would suggest that the Henderson Lake walleye are abundant, however, with only 25 percent of their former abundance, the population could be easily collapsed with little fishing pressure.

Prediction of Time to Recovery

Model A was within the confidence limits of the Schumacher-Eschmeyer estimate of 871 walleye. Model B predicted 1213 walleye in 1995 which was greater than the Schumacher-Eschmeyer estimate but still within the 95 percent confidence limits.

The prediction of time to a complete recovery was not possible for model A which reached a horizontal asymptote at approximately 1650 walleye as recruitment equaled natural mortality. Extrapolating 20 years beyond the pulse harvest using model B gives an estimate of 3280 walleye which better approximates the preharvest estimate of 3600. Other lakes have required similar recovery periods after being severely reduced. Both Redgut Bay and the South Arm of Rainy

Lake have not recovered after 23 and 33 years, respectively even with reduced angling pressure (Colby et al. 1994). Conversely, Lake of the Woods (Minnesota waters) and Lac Seul with reduced commercial angling recovered in 15 years (Colby *et. al.* 1994). I would have expected Henderson lake to recover more quickly since it was closed to all angling.

These models seem to oversimplify the dynamic changes that occur in a lake. However, with better estimates of mortality, population numbers, and fecundity, some predictive capability may emerge. I felt this was a superior method to predict time to recovery than simply extrapolating from population estimates. The utility of this procedure as a tool for fisheries managers will be determined through application to other data bases.

Management Implications

A high removal of a single species (~90 %) from a lake has a significant impact on the remaining fish community and the ecosystem as a whole. If complex systems were predictable and linear in response to perturbations, pulse fishing would be easy to evaluate. To decide whether pulse fishing is a viable management alternative for a northern walleye lake the following questions must be asked (modified from Kay 1990): Will the harvest be sufficient to cause a catastrophic disappearance of walleye from the lake? Will the walleye population return to preharvest level or will northern pike and yellow perch displace the walleye, and if so, to what degree? What harvest levels would permit walleye to recover to preharvest numbers?

The possibility of population extinction is a concern at low population levels (Smith 1990). Extinction may occur when population levels are so low that inbreeding and genetic drift reduce the population's ability to withstand environmental change (Smith 1990). In Heming Lake, Manitoba where the spawning walleye population was decimated with the release of an ice jam at the mouth of the spawning creek, the population had not returned to anywhere near its former abundance after eleven years (Lawler 1965). However, the walleye did not become extinct in Henderson Lake so either the harvest was not severe enough to cause an extinction or sufficient numbers of juvenile fish, too small to be caught in the gear, were present to repopulate the lake.

At the time of this study, neither northern pike nor yellow perch had displaced the walleye to any degree although these species share similar food items and are netted together in Henderson Lake (Fig. 12, Reid and Momot 1985). A substantial removal of one species which shares common food resources with another, should improve feeding conditions for the remaining species. However, walleye tend to be more open water shoaling fish (Ryder 1977) while northern pike are usually solitary littoral zone ambush predators (Ratt 1988). Ryder and Kerr (1978) came to the conclusion that four associated species (walleye, northern pike, yellow perch, and white sucker) often tend to form an identifiable and vital subcomponent of fish communities of the Precambrian Shield region of the north temperate boreal forest zone. These species appear to be inextricably correlated, so that a high level of interspecific relationship has developed (Ryder and Kerr 1978). Colby et al. (1987) believed that factors controlling population numbers of adult northern pike and white suckers in northern lakes may still operate despite walleye reductions, suggesting less intense interaction between species than previously assumed. In a study of lakes with arctic grayling as the terminal predator it was hypothesized that simple communities (i.e. low species diversity) have a high level of integrity allowing the community to return to preharvest conditions (Johnson 1994b). In more productive waters with more diversified species composition, 'released productivity' may be assimilated by species other than percids (Colby et. al. 1994). Nevertheless, northern pike and walleye which utilize similar forage in many northern lakes must have considerable interspecific differences which permit them to coexist. Otherwise, one or the other species would have been displaced long ago due to natural events (disease, competition, droughts, etc.). Prey availability does not appear to be a factor limiting abundance of either northern pike or yellow perch in Henderson Lake.

The Henderson Lake study has shown that 90 percent walleye removal was excessive necessitating a recovery time exceeding 13 years. Unexploited lake whitefish (*Coregonus clupeaformis*) populations were harvested at various rates in northwestern Ontario (Mills and Chalanchuk 1988, and Mills et al. 1995). Lake whitefish have similar fecundity and longevity to walleye but are a cooler water species (Scott and Crossman 1973). Increased growth and recruitment was recorded for the two whitefish populations with one year harvest rates of 63 and 40 percent while only increased recruitment was recorded for another population with a one year harvest rate of 26 percent (Mills and Chalanchuk 1988). However, the time to complete recovery for whitefish populations harvested by more than 30 percent increased considerably while the population harvested at 26 percent would only take 2 to 3 years (Mills et. al. 1995).

Recommendations

The magnitude of the harvest on Henderson Lake which removed 15 years of the recommended yield in a three year period (O.M.N.R. 1982), undoubtedly slowed the recovery. An 85 percent or greater removal of coarse fish is recommended to aid in successful species introductions (Colby et. al. 1987). This further illustrates that a 90 percent removal in Henderson Lake was excessive. Although walleye in Henderson Lake have high fecundity with females producing approximately 50 000 eggs per kilogram (Reid 1985), very high mortality is experienced, especially within the first year of life. Wisenden (1988) documented increased production, growth and fecundity of northern pike with a dramatic increase in yellow perch numbers in 1985 and 1986. An increase of these species which share some resources and habitat, likely slowed the walleye recovery.

A better idea of allowable harvest is needed for pulse fishery management. Based on the MEI for Henderson Lake, the OMNR guidelines (1982) recommend 1.5 kilograms of walleye per hectare per year for a sustainable angling fishery. Research on nearby Savanne Lake revealed that to retain fishing quality (consistent CUE) a sustained harvest must be less than recommended in the guidelines (Colby and Baccante 1996). It is essential that the pulse harvest should be a function of the desired time to recovery. Ideally, the harvest would remove an amount per year for every year that the fishery is allowed to recover. The harvest would be stopped at a maximum percent of the standing crop. For example, if a lake is to recover in 5 years with a yearly production of 1 kilogram per hectare, then the one year removal might be 5 kilograms per hectare. With further research, a manager could maintain a quality fishery, reduce field work while allowing substantial yields.

For future studies, additional unperturbed control lakes should be studied concurrently. Furthermore, Henderson Lake should be monitored in the near future to see if, and at what rate, the walleye population continues to increase. Repeated pulsing at lower harvest rates may reveal what level of harvest would be more desirable.

Spring population estimates were inaccurate in this study with mature adult fish apparently dominating the spawning areas targeted by the nets. To avoid this situation additional markings are needed to identify multiple recaptures which bias the sample. In addition, catch per unit effort for the six foot trapnets should be used in conjunction with the population estimates. Researchers must be cautious of clear water lakes with limited spawning shoals as larger, older fish may dominate samples taken during the spawn.

I believe that with current budgetary restraints in Ontario that pulse fishing would be useful for economic reasons alone. A pulse fishery system consisting of a rotational harvest of numerous lakes, with sufficient recovery periods and conservative yields could be implemented. Anglers would not be denied opportunity since the closure of one or more lakes would coincide with the opening of others. Presumably with an adequate number of lakes and appropriate harvests the rotation would allow sufficient time for recovery of the pulsed lakes. Costly assessment would only be needed for lakes prior to, and immediately following the harvest. Enforcement costs would also be reduced with less lakes to monitor and easier to implement as any angler on a closed lake is fishing illegally.

The Ontario Ministry of Natural Resources is currently unable to adequately assess the numerous small lakes in northern Ontario. Additional staff and funding or co-operative agreements may be needed to operate a pulse fishery. In 1978, the Province of Quebec set up zones of controlled exploitation (ZEC) to manage certain wildlife units (Q.M.E.F. 1994). ZECs are run by non-profit organizations with management objectives that are set and monitored by the Ministry of Environment and Wildlife. The ZECs are accessible to the everyone but a daily user fee is collected to offset the costs of management and maintenance (roads, boat launches, etc.). Pulse fishing as an adaptive management tool would be amenable to partnerships; such as those incorporating angler groups, first nations, or the forestry companies who are creating access to these lakes.

Pulse harvests occur naturally in northwestern Ontario fly-in lakes. As effort increases and yields decline outfitters switch to other lakes. When access is gained to less remote lakes anglers can quickly collapse these fisheries. Unfortunately in many cases collapsed populations have remained at low levels even after the stress causing the collapse or decline was removed (Colby et. al. 1994). With a little management these fisheries could be protected from excessive harvests, which in the case of Henderson Lake considerably delayed recovery time.

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Appendix 1 Table 1. **Tests of significant differences between mean lengths for various ages of walleye in Henderson Lake, 1982 to 1986 and 1994 to 1995.**

Age 4	Age 5	Age 6	Age 7	Age 8
1983-1995 (53[1] *+[2])	1983-1984 (90 **+)	1982-1985 (21**-)	1983-1985 (32**+)	1983-1985 (30*+)
	1984-1995 (55**-)	1983-1984 (64**+)	1983-1994 (40*+)	1983-1986 (33**+)
		1983-1985 (49**+)	1983-1995 (32*+)	1983-1994 (28*+)
		1983-1994 (53*-)	1984-1985 (35**+)	1984-1985 (29*+)
		1983-1995 (50**+)	1984-1995 (35*+)	1984-1986 (32**+)
		1984-1985 (35**+)		1986-1995 (37*-)
		1985-1994 (24*-)		

1 degrees of freedom
2 direction of change
* significant to p<.05
** significant to p<.01
1982-1984 from Reid (1985)
1985-1986 from Wisenden (1988)

Appendix 1 Table 2. Tests of significant differences between mean lengths for various ages of northern pike in Henderson Lake, 1982 to 1986 and 1994 to 1995.

Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
1983-1986 (87[1] **-[2])	1982-1985 (45**+)	1985-1986 (34*+)	1982-1985 (31**+)	1982-1986 (39*+)	1985-1986 (34*+)
1985-1986 (111*-)	1982-1995 (20**+)	1985-1995 (38**-)	1983-1986 (42**+)	1983-1986 (40*-)	
	1983-1995 (19*+)	1986-1994 (34**-)	1983-1994 (47**+)	1985-1986 (35*+)	
	1984-1985 (44*+)	1986-1995 (40**-)	1985-1995 (34*-)	1986-1995 (46*-)	
	1984-1995 (19*+)		1986-1994 (43*+)		
	1985-1995 (45**-)		1986-1995 (44**-)		
	1986-1995 (58**-)				

[1] degrees of freedom
[2] direction of change
*significant to p<.05
** significant to p<.01
1982-1984 from Reid (1985)
1985-1986 from Wisenden (1988)

Appendix 2. Total effort and CUE in lightly fished Ontario walleye Lakes (less than 5 rod hours/hectare effort, M. Freutel, O.M.N.R. Unit Biologist, Quetico-Mille Lacs Unit, Fisheries Assessment Unit, 1996).

Lake	CUE	Rod-Hours/Hectare
Allan Lake	0.561	3.20
Campbell Lake	0.861	4.10
Chandos Lake	0.025	0.40
Crowe Lake	0.054	2.80
Cuttle Lake	0.408	3.90
Eagle Lake	0.006	0.10
Eels Lake	0.030	1.33
Eltrut Lake	0.964	1.80
Flower Round Lake	0.124	0.90
Francklyn Lake	0.545	2.90
Grassy Lake	0.337	1.60
Kaiarskons Lake	0.127	1.60
Kecil	0.052	0.30
Lac Seul	1.149	1.57
Lake Nipissing	0.266	4.10
Little Trout Lake	0.931	4.70
Loonwing Lake	0.374	3.00
Mattagami Lake	0.187	1.05
Mesomikenda Lake	0.092	1.20
Minisinakwa Lake	0.267	2.25
Nagagami Lake	0.666	3.90
Nungesser Lake	1.565	4.90
Onaman Lake	1.252	0.94
Otter Lake	0.859	2.60
Pearce Lake	0.528	4.60
Relic Lake	0.667	0.10
Remi Lake	0.052	4.60
Savanne Lake[1]	0.930	2.90
Sturgeon Lake	0.602	0.50
The Steps	1.667	0.90
Trout Lake	0.529	1.20
Tube Lake	0.074	1.70
Tupman Lake	0.939	0.50
Upper Grassy Lake	0.406	2.10
Willow Island Lake	0.333	3.70
Zadi Lake	0.581	3.80

[1]Colby et al. 1987

Appendix 3. Henderson Lake Temperatures

	Surface	Bottom
June 7-30, 1994		
Maximum (^{0}C)	22	22
Minimum (^{0}C)	16	14
Average (^{0}C)	19	18
July 1-21, 1994		
Maximum (^{0}C)	21	20
Minimum (^{0}C)	17	17
Average (^{0}C)	19	18
May 7-31, 1995		
Maximum (^{0}C)	21	20
Minimum (^{0}C)	8	7
Average (^{0}C)	13	12
June 1-22, 1995		
Maximum (^{0}C)	26	26
Minimum (^{0}C)	14	12
Average (^{0}C)	20	17

Appendix 4. Savanne Lake Temperatures

	Surface Temperatures
May 16-31, 1994	
Maximum (^{0}C)	20
Minimum (^{0}C)	9
Average (^{0}C)	15
June 1-30, 1994	
Maximum (^{0}C)	27
Minimum (^{0}C)	14
Average (^{0}C)	19
July 1-31, 1994	
Maximum (^{0}C)	27
Minimum (^{0}C)	18
Average (^{0}C)	20
Aug 1-30, 1994	
Maximum (^{0}C)	34
Minimum (^{0}C)	8
Average (^{0}C)	19

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

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