Detecting trends in walleye (Stizostedion v. vitreum, Mitchill) abundance using catch-effort data

by

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submitted to the Department of Biology in
partial fulfillment of the requirements for the degree
of Master of Science

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ABSTRACT

Three methods of analyzing catch-effort data were investigated regarding their relationship to walleye abundance: mean CUE, Gini coefficient and the relative frequency of zero CUE (RFZ). Walleye recreational fishery data were obtained for Escanaba Lake, Wisconsin (1966 to 1985) and the Bay of Quinte, Ontario (1985 to 1989). A linear regression model was used to analyse the relationship of mean CUE, Gini coefficient and RFZ to walleye abundance in Escanaba Lake. Mean CUE was not linearly related to walleye abundance. The Gini coefficient was weakly correlated with abundance. RFZ correlation with walleye abundance was highly significant. Only RFZ was capable of accurately predicting walleye abundance levels.

ACKNOWLEDGEMENTS

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I especially wish to acknowledge June Steube, whose unflagging support and encouragement got me into this in the first place.

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Introduction

In 1918, Baranov formulated the classic catch equation relating catch per unit effort (CUE) to abundance. This equation has been extensively applied to fisheries data ever since (Paloheimo and Dickie 1964). CUE is the most widely used parameter evaluating both the state of fish populations and to forecast any changes in status (Beaumont et al 1991). The widespread assumption that catch data can be used as an index of abundance needs critical examination (Beaumont et al 1991, Van Den Avyle 1986, Forney 1980, Sampson 1991).

Although mean CUE continues to be used as an index of abundance in fisheries assessment (Kerr and LeTendre 1991, Van Den Avyle 1986, Sampson 1991) many studies indicate that mean CUE is not linearly related to fish abundance (Rose 1992, Peterman 1980, Peterman and Steer 1981, Reid and Momot 1985, Paloheimo and Dickie 1964, Roff 1983, Moring 1985, Bannerot and Austin 1983, Beaumont et al 1991).

Hyvarinen and Salojarvi (1991) point out that although the use of mean CUE for abundance estimation remains problematic, there are no practical alternatives. Refinements to the use of mean CUE have been proposed (Baccante and Colby 1991, Paloheimo and Dickie 1964, Gablehouse and Willis 1986, Rupp 1961) but variation in the relationship between mean CUE and abundance remains the underlying problem, discouraging its use (Paloheimo and Dickie 1964, Sampson 1991).

This study examines mean CUE, as well as two potential alternative indices of fish abundance, the Gini coefficient and the relative frequency of zero CUE (RFZ) as measures of walleye, Stizostedion v. vitreum., abundance. Each of these indices will be examined for a linear relationship with walleye abundance.

Both the Gini coefficient and RFZ are derived from frequency distributions of CUE. Many recreational fisheries have right skewed distributions of CUE (Hilborn 1985, Cryer and Maclean 1991, Bannerot and Austin 1983, Kell 1991, Rupp 1961, Morgan and Gordon 1994). The Gini coefficient, a commonly used quantifier of inequality in frequency distributions, recently has been applied in a fisheries context (Smith 1990, Baccante 1995, Colby et al 1994). The RFZ index is based on the observation that the mode of the CUE distribution is frequently at zero CUE (Bannerot and Austin 1983, Rupp 1961, Kell 1991, Morgan and Gordon 1994). Bannerot and Austin (1983) report that, for right skewed distributions, the relative frequency of the mode is far more sensitive to change in the distribution than the mean of the distribution. The frequency distribution of CUE demonstrates increased skewness with decreasing fish abundance (Bannerot and Austin 1983)

This paper compares the performance of mean CUE, the Gini coefficient and RFZ as indices of abundance for two walleye fisheries: Escanaba Lake, Wisconsin and the Bay of Quinte, Ontario. Both lakes have intensively exploited walleye fisheries.

Escanaba Lake

Walleye were first introduced to this lake in 1933. By 1947 a naturally reproducing population was established (Kempinger and Churchill 1972). Since 1946, the response of the population to liberalised fishing regulations has been measured employing a complete creel census (Serns 1982). There are no closed seasons or catch restrictions for walleye angling in Escanaba Lake and all anglers are surveyed upon leaving the lake.

Escanaba Lake is unusual in that it receives a large amount of fishing effort per hectare compared to other walleye lakes. Angling pressure on Escanaba Lake has ranged from 89 to 304 h/ha

(Kempinger and Carline 1977, Colby et al 1979). Colby et al (1979) list 36 lakes which ranged from 1.2 to 289 angling hours per hectare (h/ha). Only one other lake (Lake Francis, Minnesota) had over 200 h/ha of effort and only five other lakes had over 100 h/ha.

With the exception of heavy angling effort, in all other respects, the fishery on Escanaba Lake is typical of walleye fisheries. Mean CUE is similar to other walleye fisheries; anglers catch from 0.01 to 0.43 fish per hour of angling (Colby et al 1979). Walleye recruit to the fishery at age 3 in Escanaba ake, and mainly 3 to 7 year old fish are harvested. Elsey and Thompson (1977) report that anglers caught mainly 4 to 6 year old fish in Lac des Milles Lacs, Ontario. In Lake of the Woods, Minnesota (Schupp and Macins 1977) and Lake Nipissing, Ontario (Anthony and Jorgensen 1977), anglers harvested mainly 3 to 6 year old fish.

Bay of Quinte

The walleye fishery in the Bay of Quinte seriously declined during the 1960's and 70's. This was followed by population recovery in the late 1970's such that by the late 1980's strong year classes were being produced. The fishery, which still is expanding, responded similarly. Fishing effort between 1989 and 1991 has roughly doubled from 69 thousand to 145 thousand angling trips. The harvest has increased from 153 thousand to 189 thousand fish. Walleye angling success rates on the Bay of Quinte are among the highest in Ontario at 0.2 to 0.3 fish per hour (OMNR 1992, Kerr and LeTendre 1991, Colby et al 1991). Anglers harvest mainly 3 and 4 year old fish (Colby et al 1991).

Materials and Methods

Data Collection

The data for this thesis were obtained from the Wisconsin Department of Natural Resources (Escanaba Lake) and the Ontario Ministry of Natural Resources, Lake Ontario Fisheries Unit (Bay of Quinte).

Creel Surveys

Escanaba Lake

Escanaba Lake has an ongoing total creel survey progam which began in the mid 1940's (Kempinger and Carline 1977, Serns 1982, 1986). Anglers, upon obtaining a free permit to fish, were required to register all harvested fish upon completion of their fishing trip. Since there is only one access point to Escanaba Lake, all anglers are surveyed upon leaving the lake. This generates essential and exact information on both harvest and effort levels exerted in the fishery.

Data for the open water season (April through October inclusive) were analyzed for direct comparison with past studies of walleye angling. These data were further subdivided into seasonal categories: spring (April to June), summer (July and August) and fall (September and October). Walleye exhibit behavioural and distributional differences over the year (Serns and Kempinger 1981). Creel data were obtained for the years 1966 to 1985. Two years were excluded from the analysis: 1975 had data entry errors and 1984 provided anomalous effort levels (S. Newman, WDNR, pers comm). An article in a popular fishing magazine resulted in a large influx of anglers and an unusually high level of angler effort.

Walleye population estimates were carried out by the Wisconsin Department of Natural Resources (WDNR) (S. Newman, WDNR, pers comm). Population estimates were derived from Petersen mark-recapture studies for most years. Walleye were tagged in the spring and the angler harvest was monitored for tags during the year. Confidence intervals (95%) were estimated at two times the standard error (SE) of the estimate. Confidence intervals could be directly calculated only for the period 1980 to 1985. Virtual population analysis generated walleye population estimates for the years 1970, 1971, 1973, 1976, and 1978. Population estimates were for the portion of the population vulnerable to angling, from age 3 to over 8 years old (S. Newman, WDNR, pers comm).

Bay of Quinte

The Bay of Quinte creel survey was a roving survey (T. Stewart, OMNR, pers comm). The anglers were interviewed during their fishing trip and provided information on the length of trip and harvest at the time of the interview. This method is considered to produce unbiased estimates of angler effort and harvest (Malvestuto et al 1978).

Open water creel data were used in the analysis in order to be consistent with the Escanaba Lake analysis. Five years of creel data were provided (1985 through 1989). Walleye population estimates were calculated by the Ontario Ministry of Natural Resources (OMNR) using the Petersen mark-recapture method (T. Stewart, OMNR, pers comm).

Since only five years of data were available for the Bay of Quinte, they were used mainly to corroborate trends in the Escanaba Lake data set. The Bay of Quinte data set was largely excluded from further analysis due to the small number of data points.

Angler Effort and Harvest

Angler effort and harvest data from both studies were used to generate frequency distributions of angler catch per unit effort (CUE). Starting at zero, the distributions were increased in increments of 0.1 CUE up to a CUE of 1.9 fish per hour. All CUE over 2 fish per hour were pooled as 2+ (see Figs 1 and 2). A CUE of 2 or more was a rare event (0 to 1.8% of anglers). Catch per unit effort was calculated simply as the individual angler's harvest divided by the trip length. See Appendix A for CUE distribution data for Escanaba Lake. Too few Bay of Quinte data points were available for population prediction analysis.

Population Predictors

Three main predictors of fish abundance generated from the catch-effort data were compared. Two of the predictors (relative frequency of zero CUE and Gini coefficients) make use of the demonstrated inequality of catch in recreational fisheries. The third, mean CUE, a traditional use of catch-effort data, has been widely used as an indicator of fish abundance. The three predictors were compared for their ability to predict walleye abundance in Escanaba Lake.

Relative Frequency of Zero Catch Per Unit Effort

Bannerot and Austin (1983) calculated the absolute number of unsuccessful anglers (zero CUE) as a percentage of the angler population for that year. This percentage is called the relative frequency of zero CUE (RFZ). The square root and natural log transformations of RFZ were calculated as well. Bannerot and Austin (1983) found that the untransformed RFZ, as well as the square root and the natural log transforms of RFZ, explained far more variation in catch-effort data than did mean CUE.

Gini Coefficients

Gini coefficients were calculated for the frequency distributions of CUE using a BASIC program supplied by Dr. P.F. Lee (Biology Dept. L.U.). Gini coefficients, a measure of the inequality in a distribution, have been used extensively by economists to quantify income distribution inequality. Recently, Gini coefficients have been used in a fisheries context (Smith 1990, Baccante 1995, Colby et al 1994).

Mean Catch Per Unit Effort

Mean catch per unit effort (CUE) was calculated as the sum of the catch divided by the sum of the effort. This is a standard method of calculating CUE.

Smoothing and Regression Analysis

Smoothing and regression analysis were carried out on the Escanaba Lake data set. The data set was divided into two parts: a model building part and a predictive part. This technique was recommended by Roff (1985) as an optimal method for testing the predictive ability of a dataset. This was not possible on Bay of Quinte data due to too few data points.

All the data generated (RFZ, CUE and Gini) were plotted against the estimates of walleye population size obtained from WDNR. A LOWESS smoothing routine (Blank et al 1985) was used to determine whether the data were linearly related to the population estimates. LOWESS smoothing objectively reveals functional relationships in scatterplots. This method for finding smoothed values uses a locally weighted robust regression (Blank et al 1985, Chambers et al 1983, Cleveland 1981). (This technique was recommended by Dr. K. Brown, Forestry Dept., Lakehead University). Smoothing time series data to detect trends is a common technique (Rose 1982, Farmer et al 1994). Moving averages often are used (Rose 1982) but this requires equal interval data. LOWESS smoothing takes into account unequal interval values (walleye population estimates) when smoothing ordinate data (RFZ, Gini and mean CUE) (Blank et al 1985).

The smoothed data points were used in linear regression analysis to obtain equations for predicting population levels. Following the recommendation of Roff (1985), the data set for Escanaba Lake was divided into two equal portions from 1966 to 1974 and from 1976 to 1985. The 1976-85 data set was used in the linear regression analysis and the resulting equations were used to predict the 1966-74 walleye population sizes. A t-test was used to determine the significance of these predictions.

Results

Frequency Distributions

The frequency distributions of walleye angler catch per unit effort for Escanaba Lake (Fig 1 and 2a) and the Bay of Quinte (Fig 2b) have the mode at zero CUE in all years. A secondary peak typically is found between 0.2 and 0.5 fish per hour of angling.

The percentage of unsuccessful anglers was lower in the Bay of Quinte study than in Escanaba Lake. In Escanaba Lake, the relative frequency of zero CUE (RFZ) fluctuates between 65 and 85% while the Bay of Quinte values are between 45 and 65%. Following the analysis of Bannerot and Austin (1983) the absolute frequency of zero CUE is expressed as a percentage of the angling population.

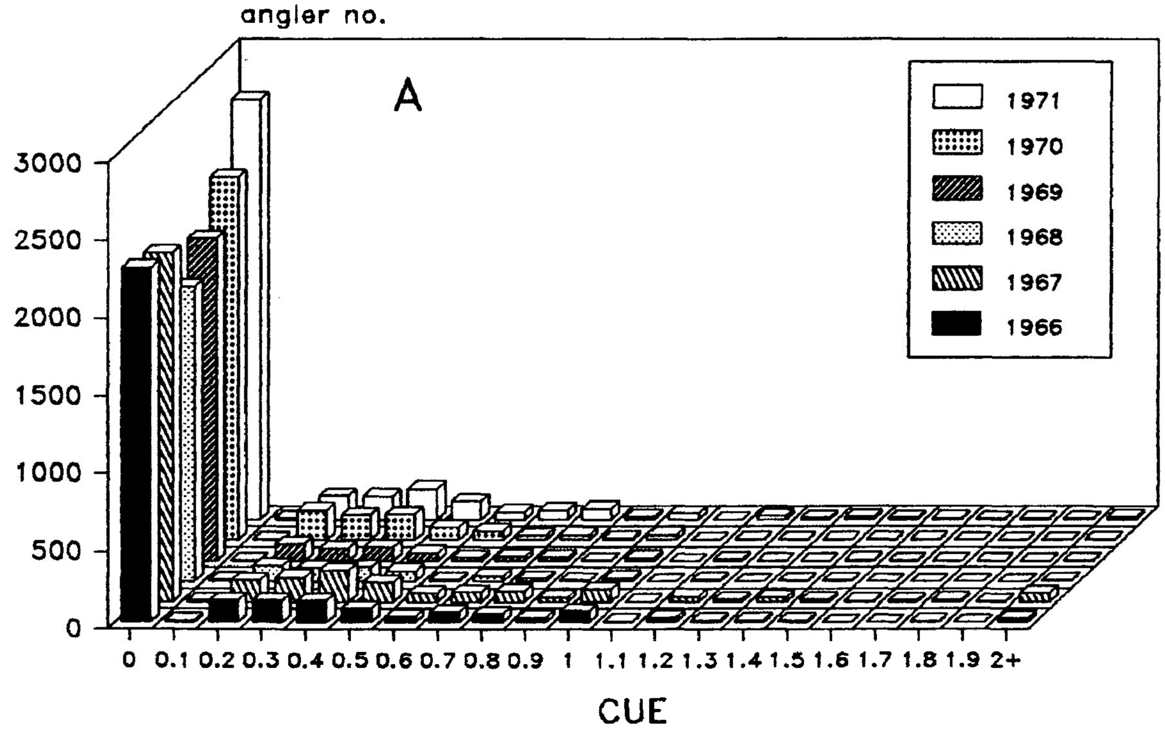
Walleye Population Estimates

Walleye populations ranged from about 3000 to 9000 fish in Escanaba Lake (Fig 3) and between 0.5 to 1.1 million in the Bay of Quinte (Fig 4). Both walleye populations showed the considerable fluctuations in population size which are typical for this species. Walleye abundance was determined by annual Petersen population estimates in both Escanaba Lake and the Bay of Quinte. The 95% confidence intervals for the Escanaba Lake walleye population estimates (1980 to 1985 only) varied from 15 to 38% (Fig 3b).

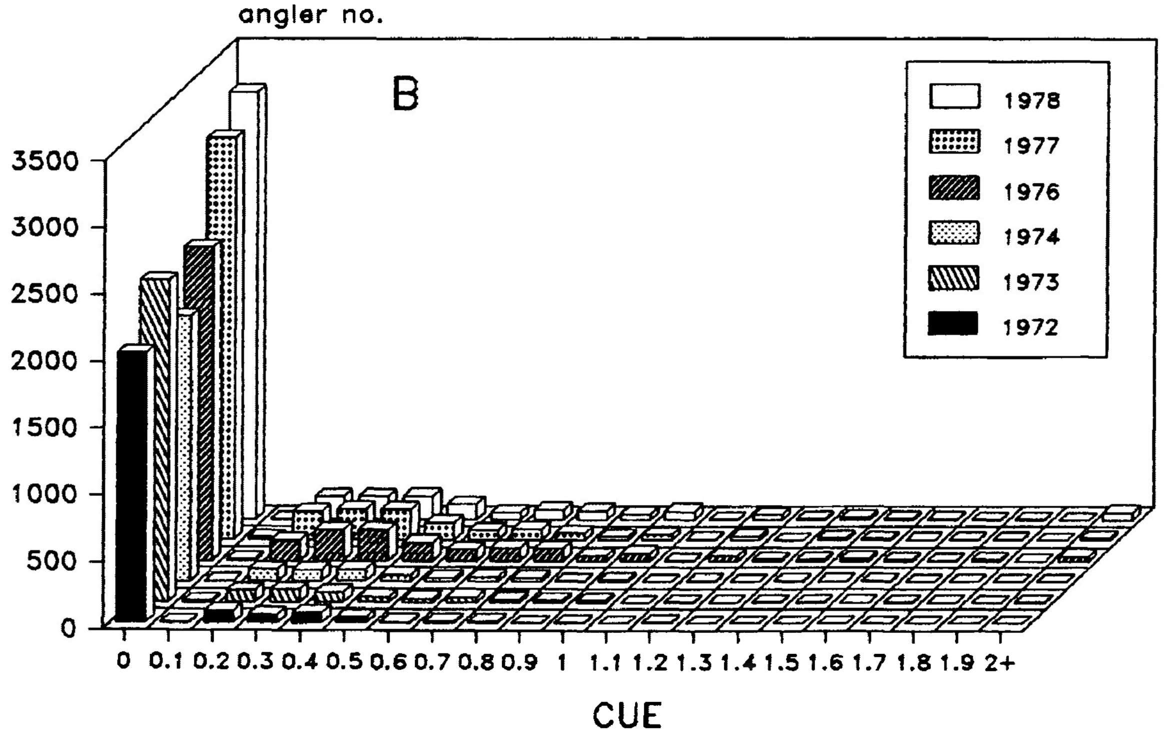
Figure 1 : Frequency distributions of walleye catch per unit effort for 1966 through 1978 on Escanaba Lake, Wisconsin.

A - 1966 to 1971

B - 1972 to 1978

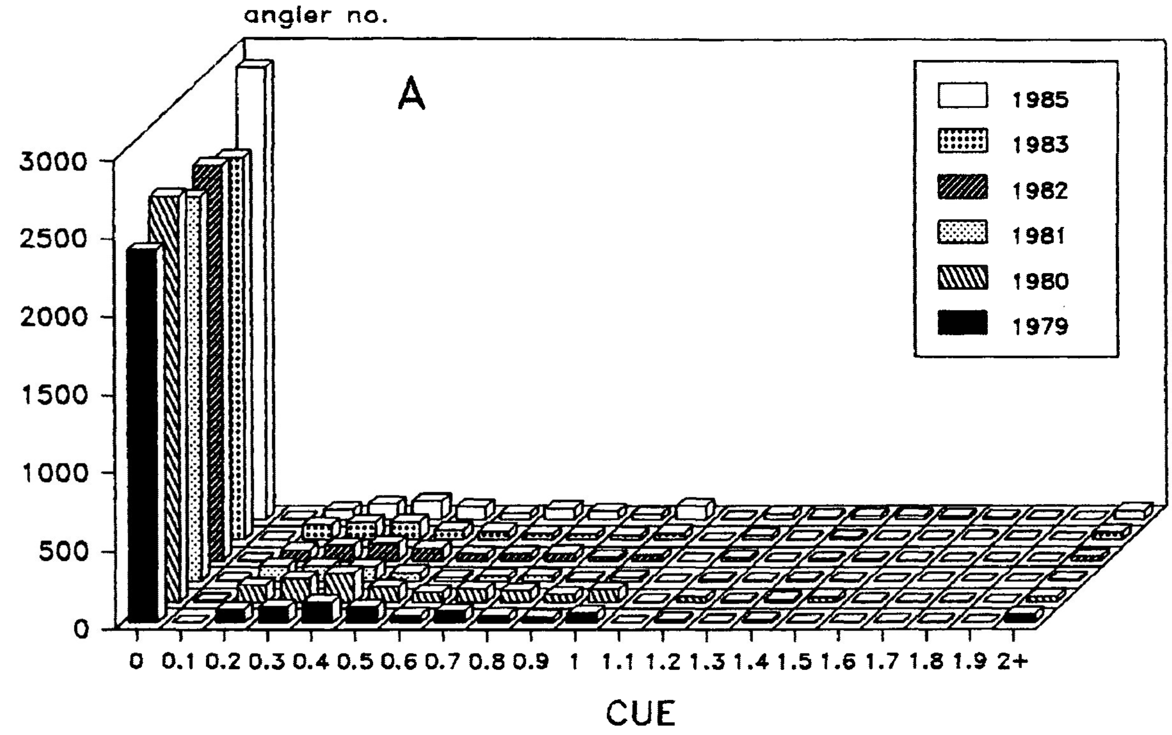


angler no.
A
3000
2500
2000
1500
1000
500
0
1971
1970
1969
1968
1967
1966
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2+
CUE



angler no.
B
3500
3000
2500
2000
1500
1000
500
0
1978
1977
1976
1974
1973
1972
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2+
CUE

Figure 2 : Frequency distributions of walleye catch per unit effort (CUE) for 1979 through 1985 on Escanaba Lake, Wisconsin (A) and for 1985 to 1989 on the Bay of Quinte, Ontario (B)


angler no.
A
1985
1983
1982
1981
1980
1979
3000
2500
2000
1500
1000
500
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2+
CUE

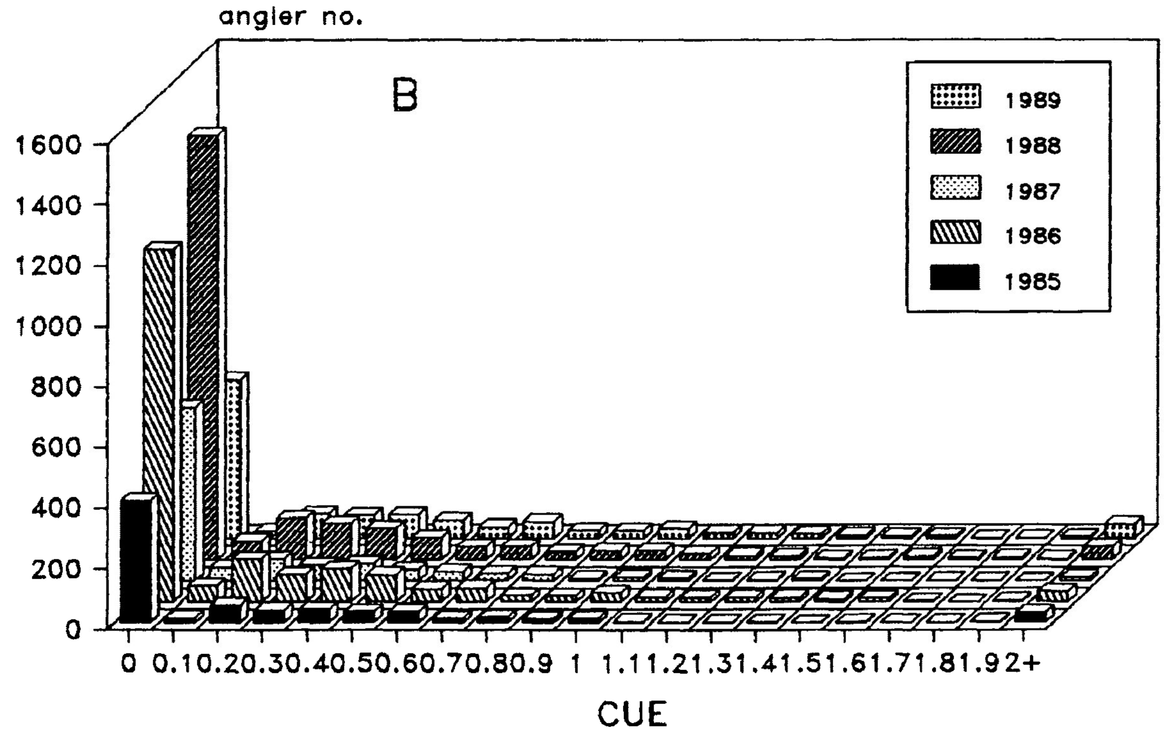
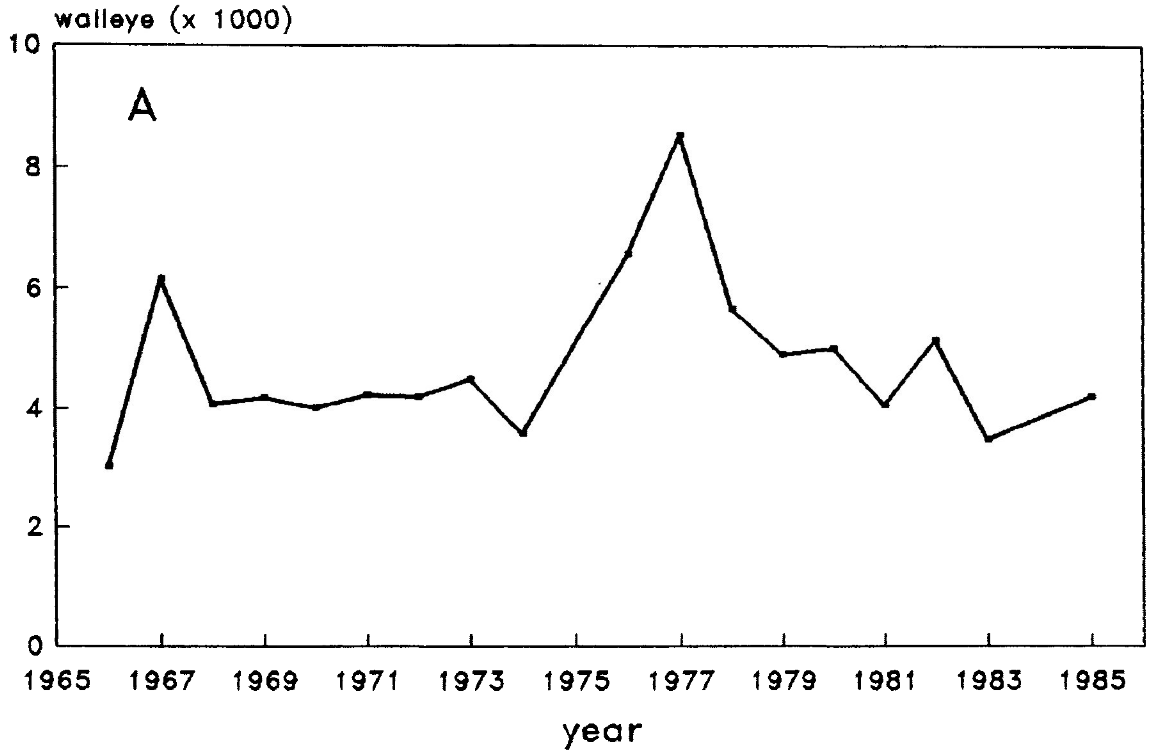

angler no.
B
1989
1988
1987
1986
1985
1600
1400
1200
1000
800
600
400
200
0
0 0.10.20.30.40.50.60.70.80.9 1 1.11.21.31.41.51.61.71.81.92+
CUE

Figure 3 : Petersen mark-recapture estimates of walleye population levels in Escanaba Lake, Wisconsin for 1966 through 1985 (A) and for 1976 - 1985 (B) Confidence intervals (95%) were available for only for the years 1980 to 1985.


walleye (x 1000)
A
10
8
6
4
2
0
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
year

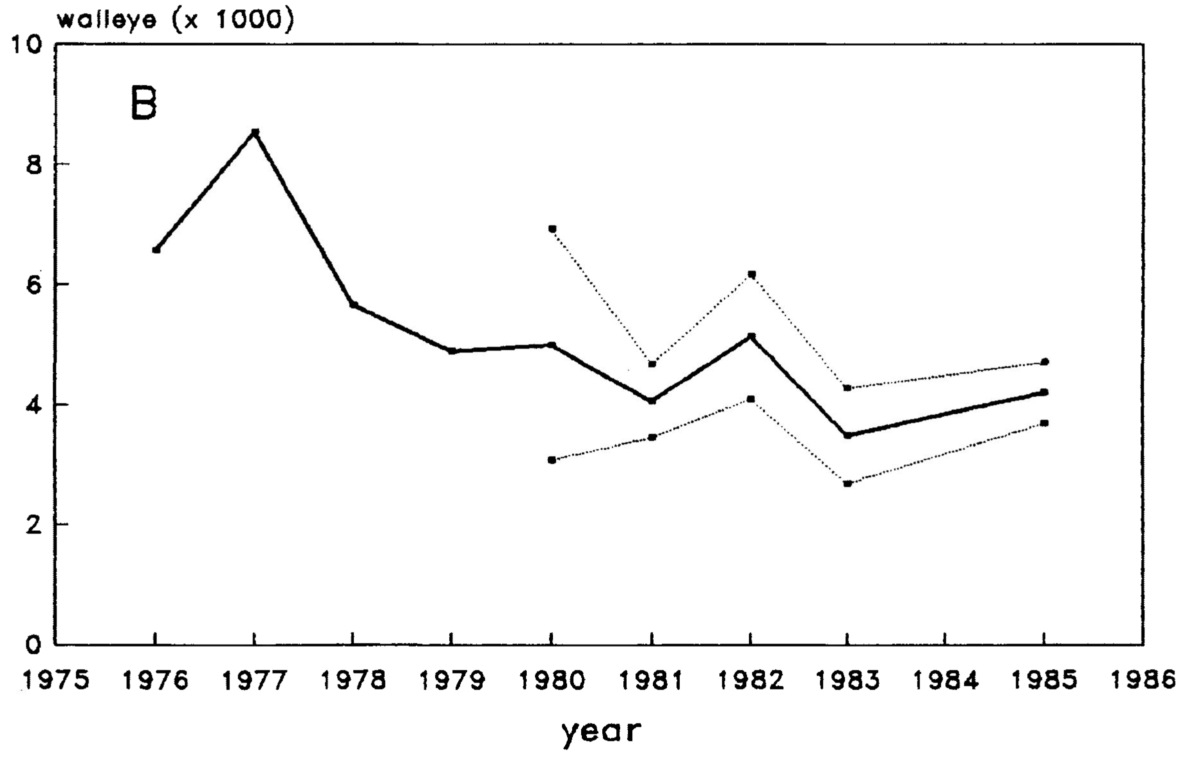
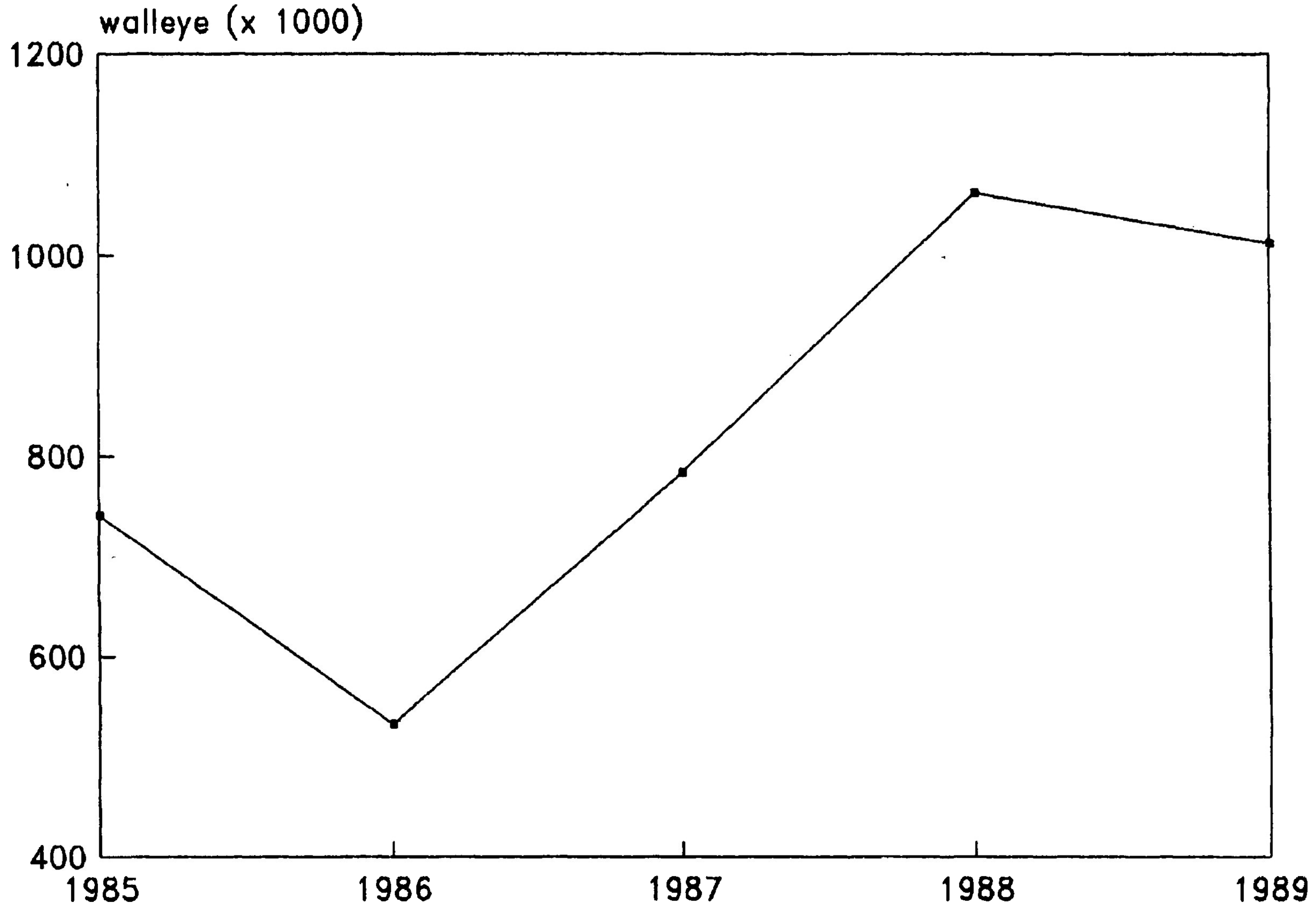

walleye (x 1000)
B
10
8
6
4
2
0
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
year

Figure 4 : Mark-recapture estimates of walleye population levels in the Bay of Quinte, Ontario. 1985 through 1989.


walleye (x 1000)
1200
1000
800
600
400
1985
1986
1987
1988
1989

Prediction of Population Size

Smoothing

As described in Methods, the data for Escanaba Lake were divided into two parts: one for model building and one for prediction. The data for the years 1976 to 1985 were smoothed with LOWESS and linear regression was used to derive a predictive equation of the form <population = constant + m(parameter)>. Figs. 5 to 9 display the smoothed data.

RFZ (Fig. 5), square root RFZ (Fig. 6a) and natural log RFZ (Fig. 6b) all show the same decreasing trend with increasing walleye abundance. Smoothed Gini coefficients exhibit a slight decreasing trend with increased walleye abundance (Fig. 7). Mean CUE displays a large degree of curvature in the data (Fig. 8). Mean CUE seems to peak at a population level of about six thousand walleye and then decline slightly.

Seasonal comparisons indicate that spring (Fig. 9a) and summer (Fig. 9b) RFZ values show similar declining trends to whole year RFZ values. Spring RFZ values are lower than summer values indicating more individual angling success in the spring fishery. Fall RFZ values (Fig. 9c) are very scattered and show a curvilinear relationship with abundance when smoothed.

Bay of Quinte

Both RFZ (Fig. 10) and Gini coefficients (Fig. 11) appear to illustrate weak but declining trends with increasing walleye population levels while mean CUE (Fig. 12) seems to display a slightly rising but non-significant trend. The relationship to walleye abundance is unclear due to the large variance in the data and the few data points.

Regression Analysis

Figure 5 : Relative frequency of zero CUE (RFZ) versus walleye population size (1976 to 1985). Observed (.) and smoothed (+) data for Escanaba Lake, Wisconsin.

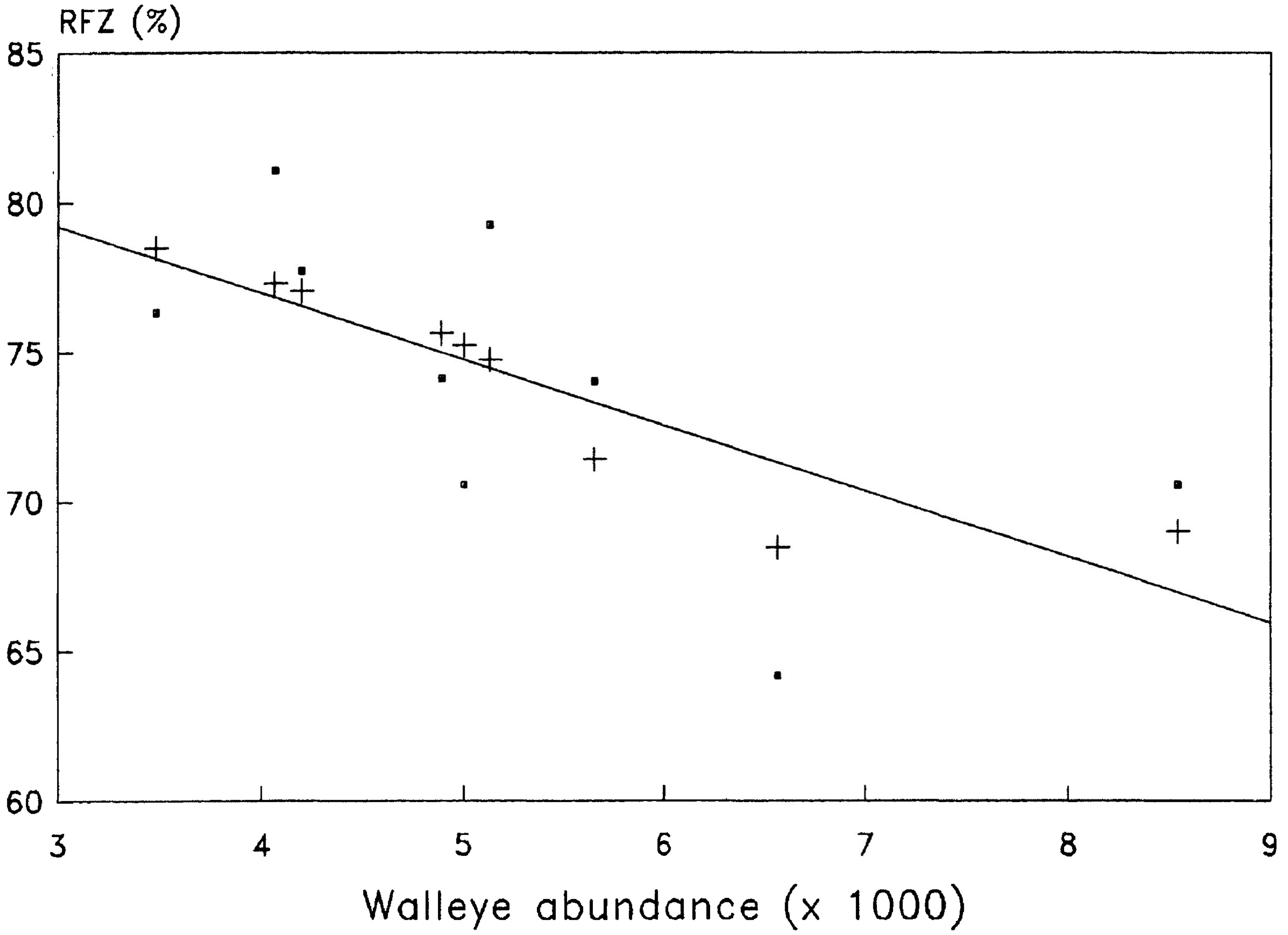
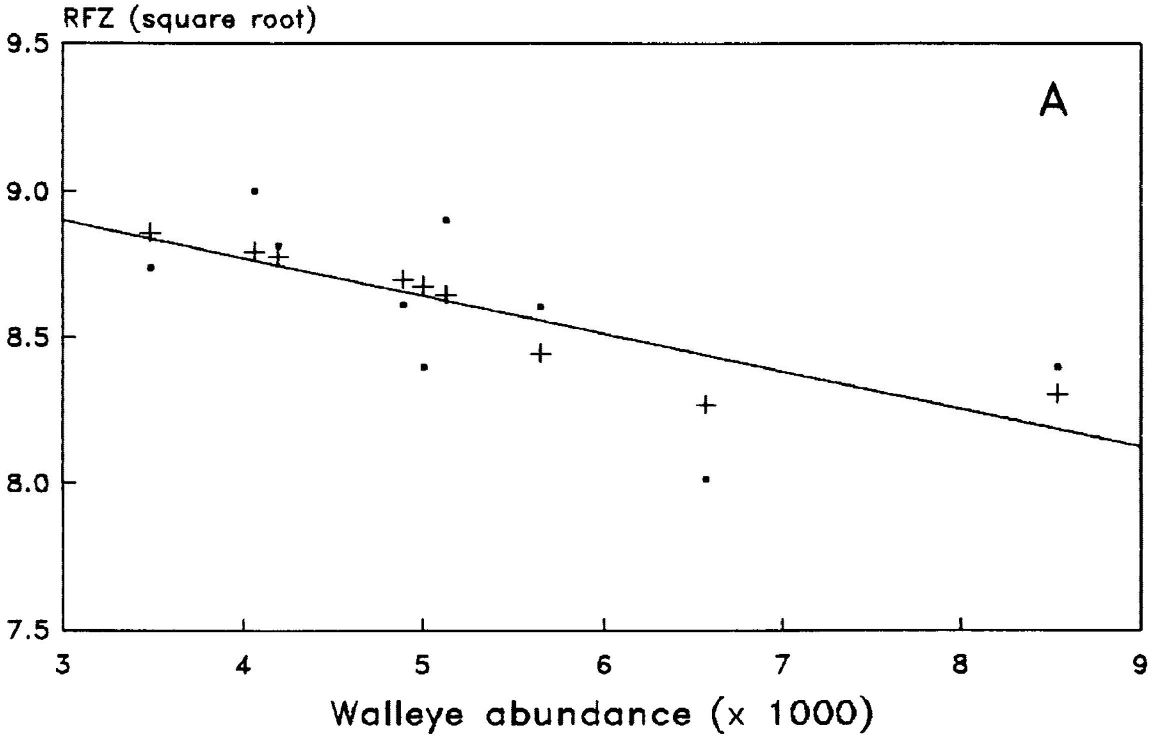

RFZ (%)
85
80
75
70
65
60
3
4
5
6
7
8
9
Walleye abundance (x 1000)

Figure 6 : A - Square root transform of the relative frequency of zero CUE (RFZ) versus walleye population size (1976 to 1985). Observed (.) and smoothed (+) data for Escanaba Lake, Wisconsin.

B - Logarithm transform of the relative frequency of zero CUE (RFZ) versus walleye population size (1976 to 1985). Observed (.) and smoothed (+) data for Escanaba Lake, Wisconsin.


RFZ (square root)
9.5
9.0
8.5
8.0
7.5
A
3
4
5
6
7
8
9
Walleye abundance (x 1000)

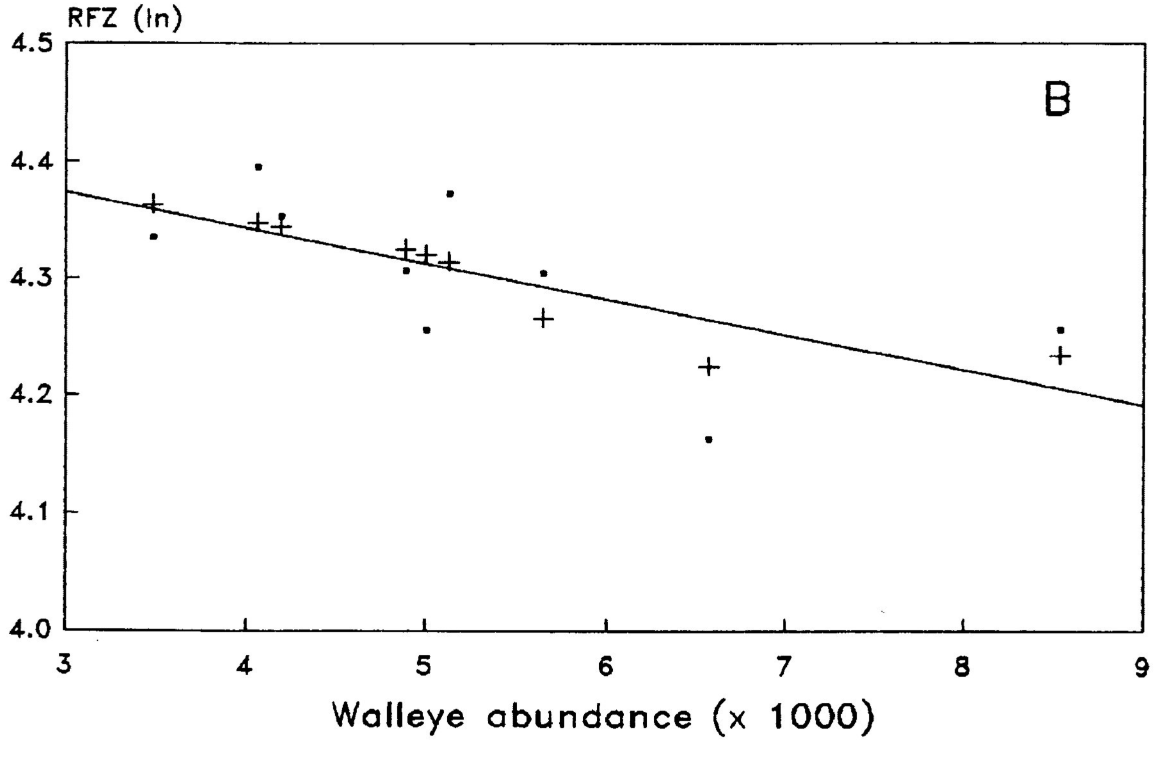

RFZ (ln)
4.5
4.4
4.3
4.2
4.1
4.0
B
3
4
5
6
7
8
9
Walleye abundance (x 1000)

Figure 7 : Gini coefficients versus walleye population size (1976 to 1985). Observed (.) and smoothed (+) data for Escanaba Lake, Wisconsin.

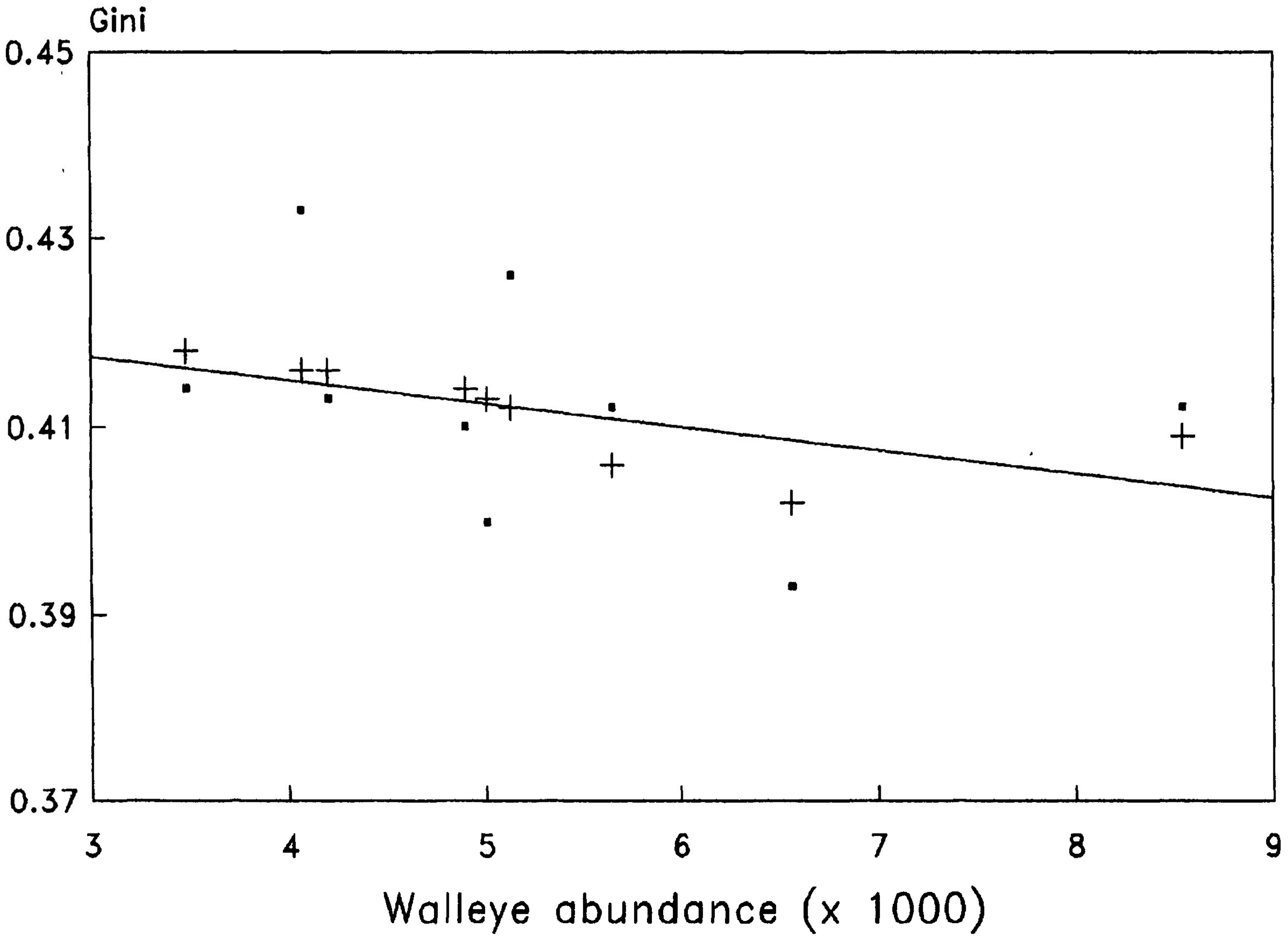

Gini
0.45
0.43
0.41
0.39
0.37
3
4
5
6
7
8
9
Walleye abundance (x 1000)

Figure 8 : Catch per unit effort (CUE) versus walleye population size (1976 to 1985). Observed (.) and smoothed (+) data for Escanaba Lake, Wisconsin.

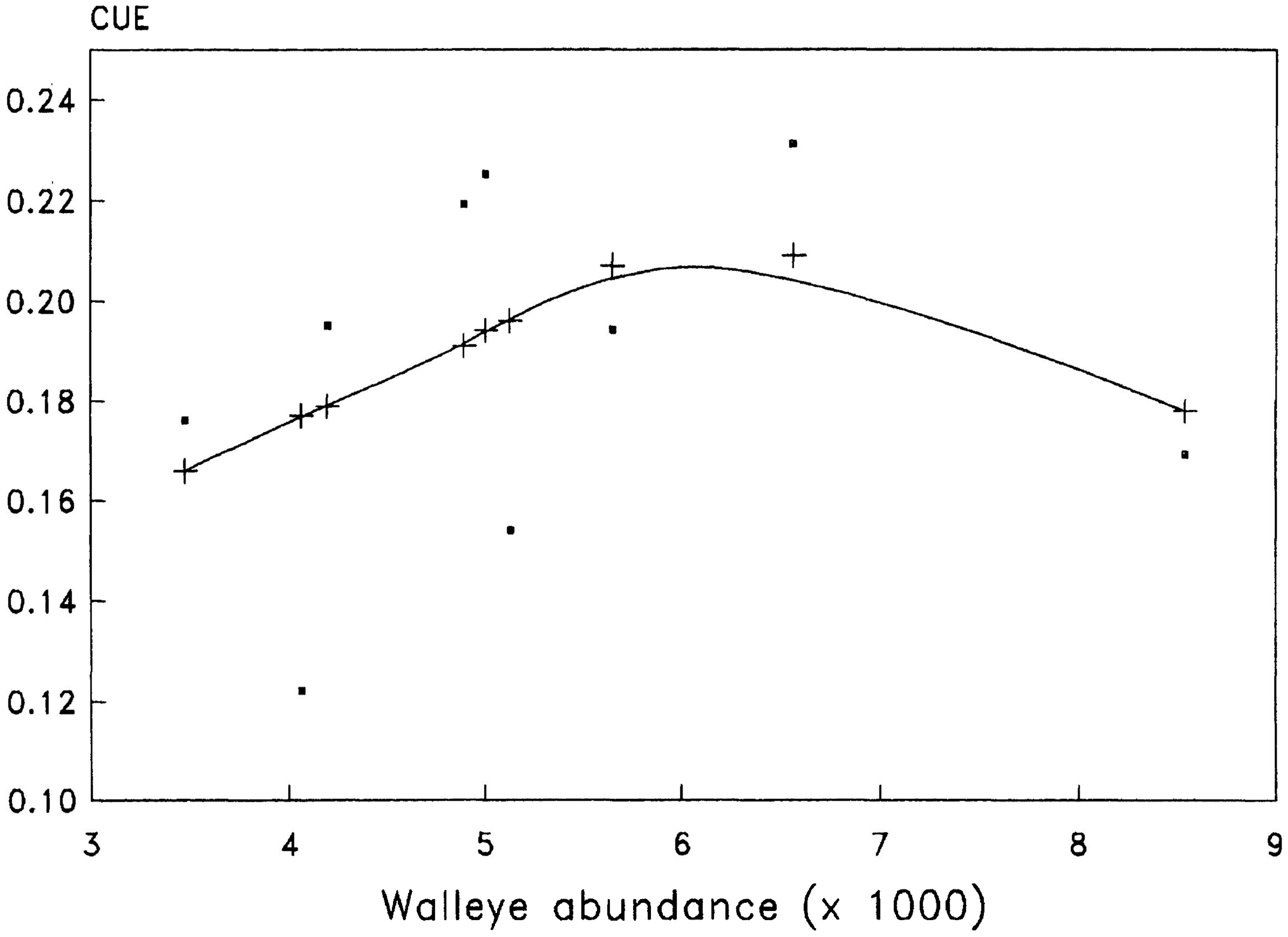
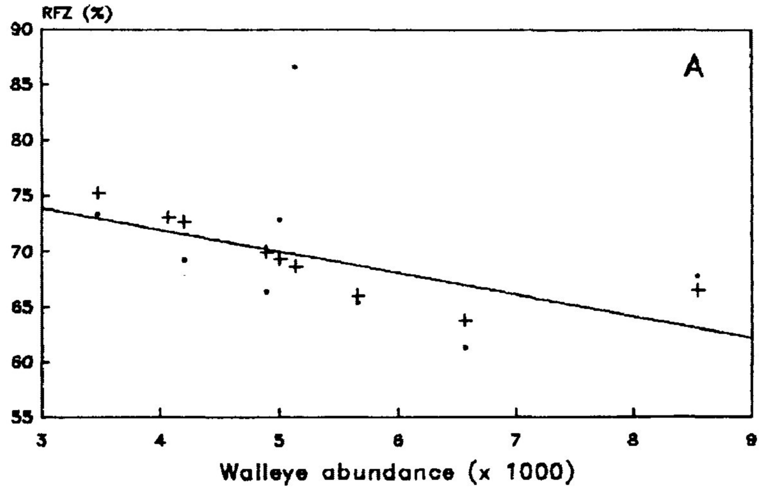
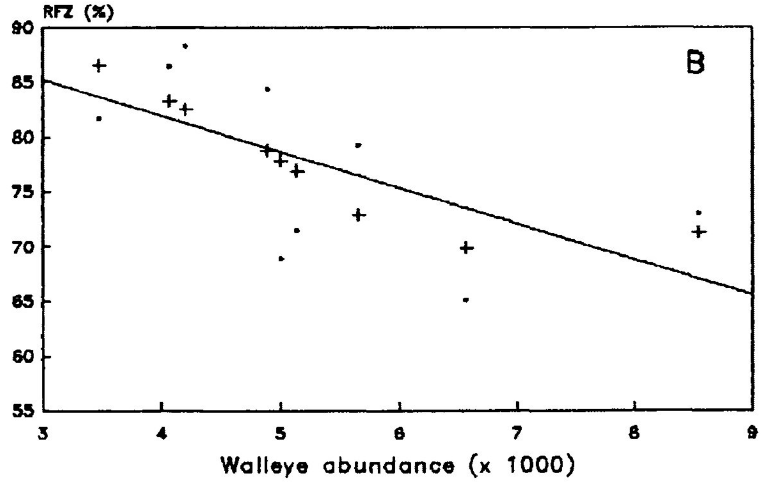

CUE
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
3
4
5
6
7
8
9
Walleye abundance (x 1000)

Figure 9 : A - Relative frequency of zero CUE (RFZ) for spring (April - June) versus walleye population size (1976 to 1985). Observed (.) and smoothed (+) data for Escanaba Lake

B - Relative frequency of zero CUE (RFZ) for summer (July - August) versus walleye population size (1976 to 1985). Observed (.) and smoothed (+) data for Escanaba Lake

C - Relative frequency of zero CUE (RFZ) for fall (September - October) versus walleye population size (1976 to 1985). Observed (.) and smoothed (+) data for Escanaba Lake, Wisconsin.


RFZ (%)
A
90
85
80
75
70
65
60
55
3
4
5
6
7
8
9
Walleye abundance (x 1000)


RFZ (%)
B
90
85
80
75
70
65
60
55
3
4
5
6
7
8
9
Walleye abundance (x 1000)

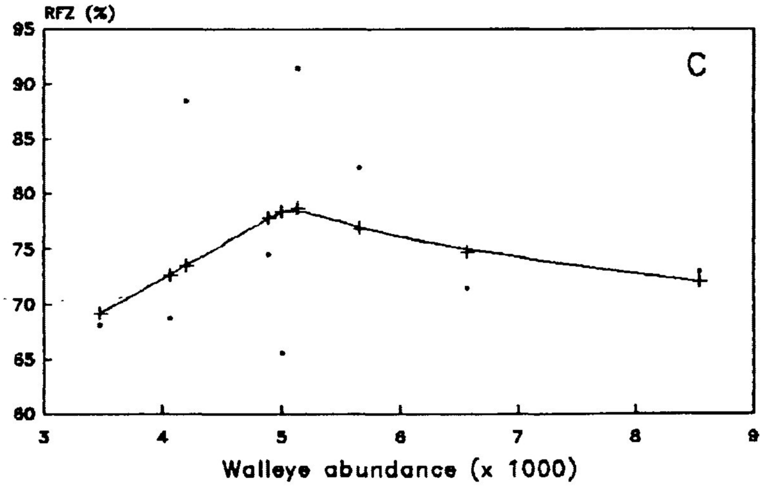

RFZ (%)
C
95
90
85
80
75
70
65
60
3
4
5
6
7
8
9
Walleye abundance (x 1000)

Figure 10: Relative frequency of zero CUE (RFZ) versus walleye population size for the Bay of Quinte, Ontario (1985 - 1989).

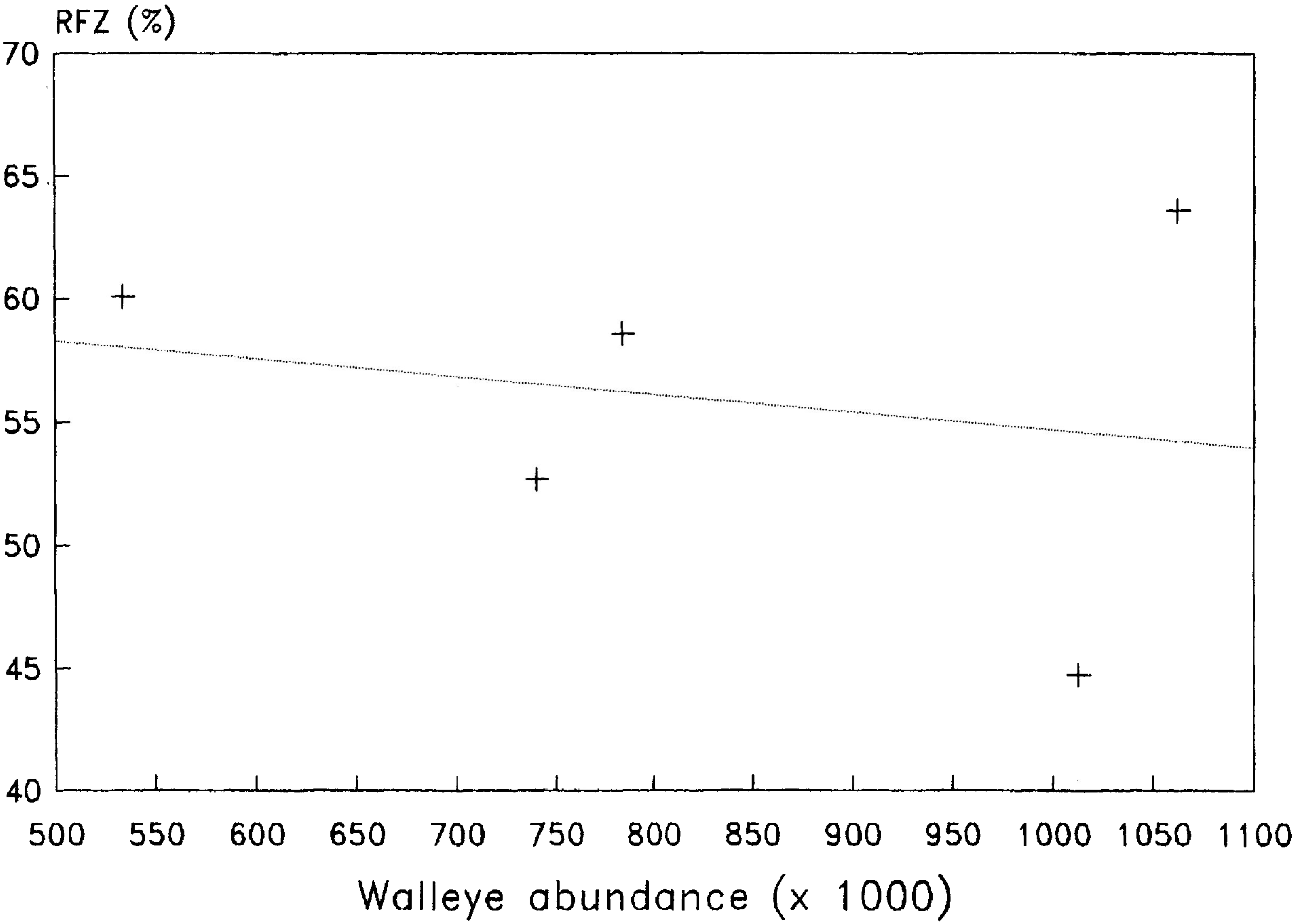

RFZ (%)
70
65
60
55
50
45
40
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
Walleye abundance (x 1000)

Figure 11: Gini coefficients versus walleye population size for the Bay of Quinte, Ontario (1985 - 1989).

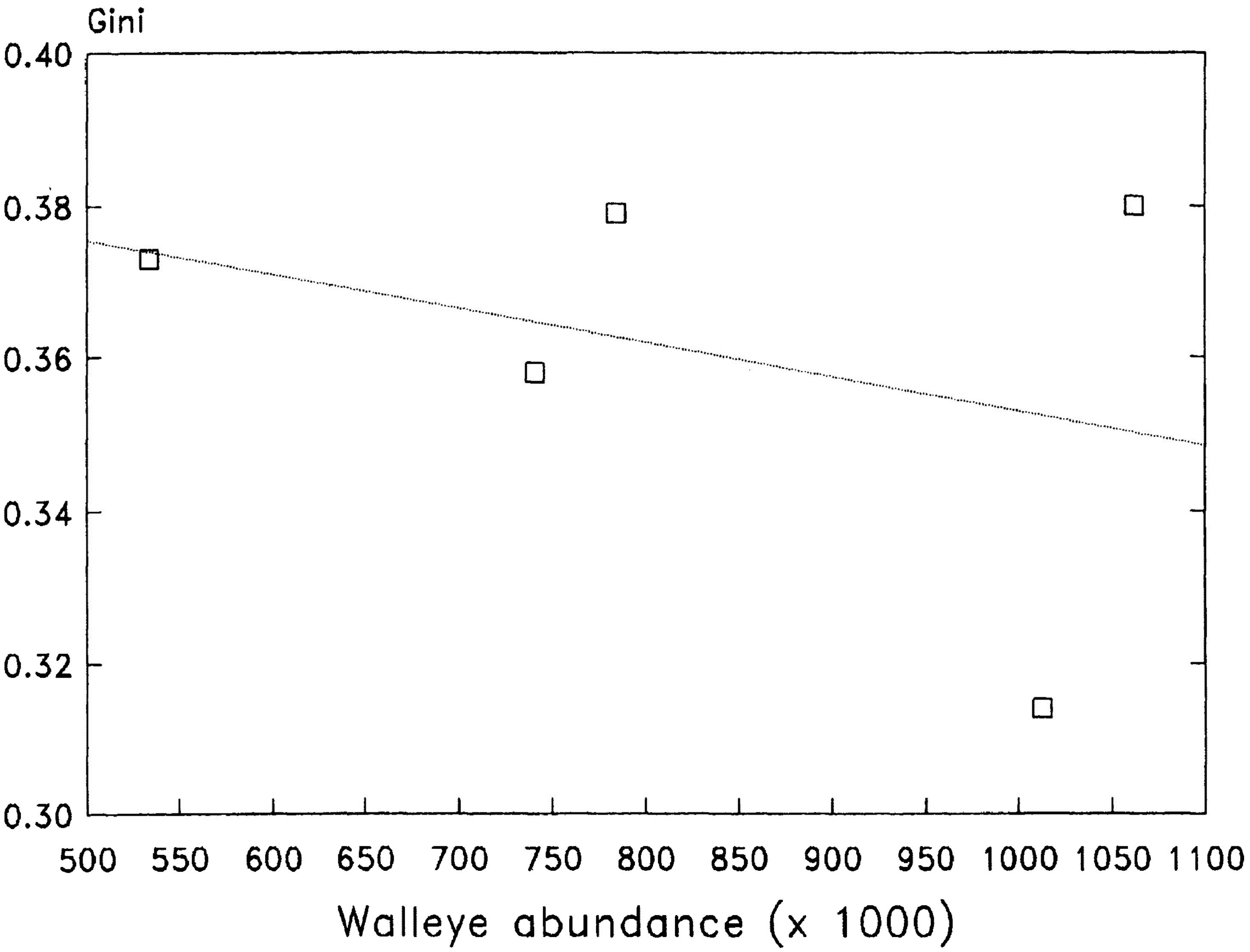

Gini
0.40
0.38
0.36
0.34
0.32
0.30
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
Walleye abundance (x 1000)

Figure 12: Catch per unit effort (CUE) versus walleye population size for the Bay of Quinte, Ontario (1985 - 1989).

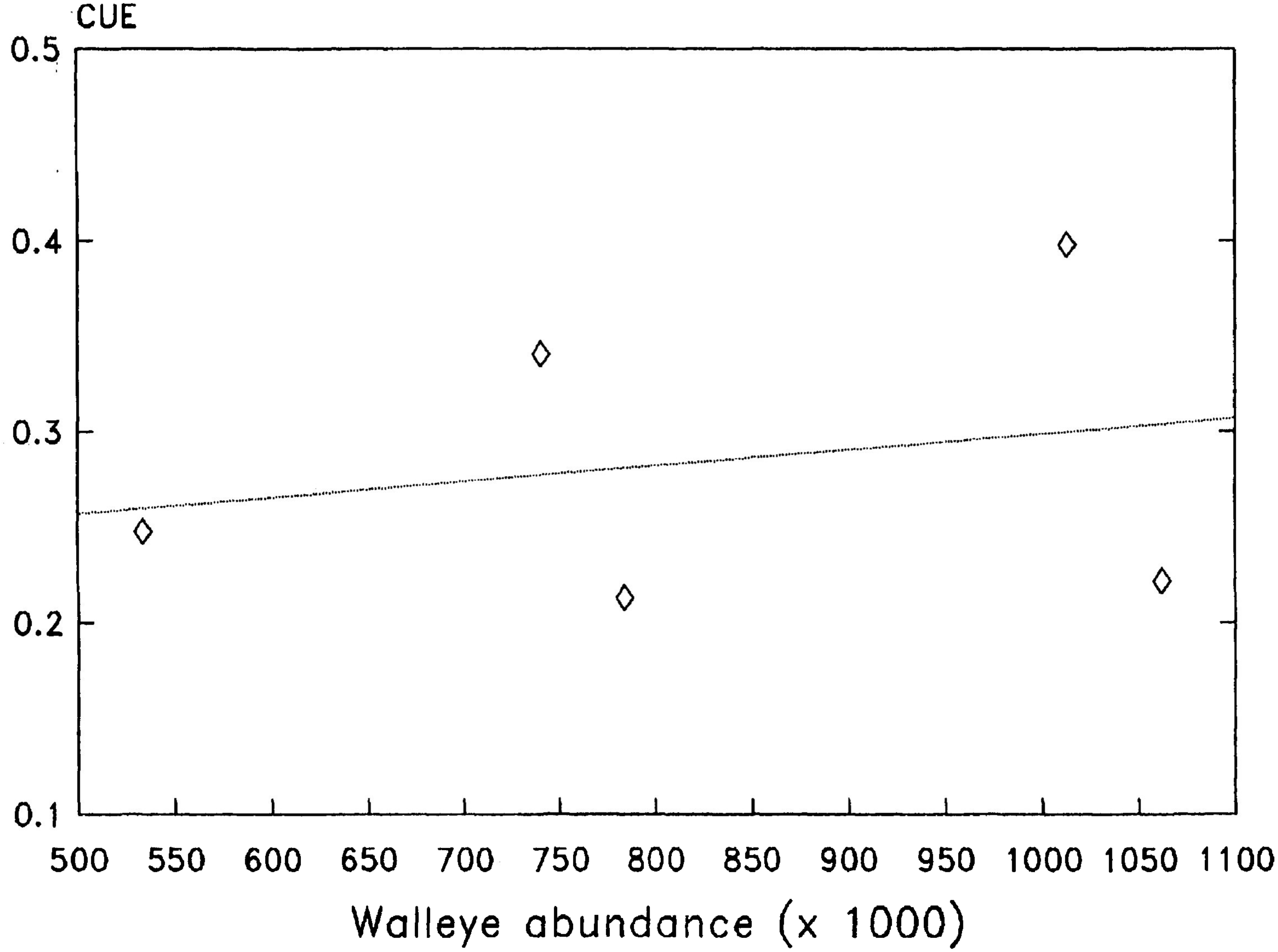

CUE
0.5
0.4
0.3
0.2
0.1
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
Walleye abundance (x 1000)

Table 1: Regression coefficients for RFZ, square root of RFZ (RFZ sqrt), natural log of RFZ (RFZ ln), Gini coefficient and mean CUE as predictors of walleye population size, Escanaba Lake, Wisconsin

X	b	m	r2	p	n
RFZ	33482.718	−380.272	0.840	0.001	9
RFZ (sqrt)	122650.182	−27269.209	0.830	0.001	9
RFZ (ln)	60737.493	−6443.063	0.835	0.001	9
Gini	98236.271	−225712.333	0.557	0.021	9
CUE	1247.181	34637.715	0.111	0.382	9

regression equation − $N = mX + b$
N = walleye population size
n = sample size

The results of the regression analysis performed on Escanaba Lake data are found in Table 1. The RFZ regressions (untransformed and transformed) are all highly significant ($p = 0.001$) and with similar r^2 values (0.83 - 0.84). The sample size is nine (1976 through 1985, excluding 1984). The untransformed RFZ had the highest r^2 values indicating that it explained more of the variation in the data than the transformed values. The seasonal regressions were significant for summer and spring, but not fall (Table 2).

The Gini coefficient regression, while significant ($p < .05$), had a r^2 of 0.557, the lowest of all the significant regressions (i.e. explained only 56% of the variance).

The regression of mean CUE was not significant ($p >> 0.05$). The smoothing results (Fig. 8) suggest that mean CUE has a curvilinear rather than a linear relationship with increasing population.

The significant regressions were employed in an attempt to predict the walleye population sizes for the years 1966 to 1974. The Petersen population estimate was used with the 38% confidence interval for comparison with the predictions.

All the RFZ regression equations produced very similar predictions (Figs. 13 and 14). Six of the nine population predictions were within the 95% confidence intervals. They also correctly predicted a peak in population size for 1967 and then oscillated around the relatively constant population size from 1968 through 1974.

Seasonal RFZ regression equation predictions were also substantially within the confidence intervals. Spring RFZ predictions of population size (Fig. 15a) tended to generate more extreme values than whole year or summer predictions. Summer RFZ predictions were closer to the observed estimates of population size with seven of the nine predictions well within the 95% confidence intervals (Fig. 15b). However, the predictions from the summer RFZ regression did not show the 1967 population peak.

The population predictions of the Gini regression equation produced the poorest fit with the Petersen estimates of walleye population size (Fig. 16). Only one of the predictions was within the 95% confidence intervals and five of the predictions were at or below zero population levels.

The regression of mean CUE, being non-significant, was not used to predict walleye population levels.

Significance

The regression estimates of walleye abundance were compared to the Petersen estimates by t-test (Table 3). The RFZ and square root RFZ predictions were statistically indistinguishable from the Petersen estimates (probabilities exceeding 95%). Natural log RFZ values gave a probability of 94% . Seasonal RFZ predictions and Gini coefficient predictions were found to give probabilities ranging from 11% (Gini) and 32 to 68% (seasonal RFZ).

Figure 13: Predicted walleye abundance from RFZ regression compared with Petersen estimated walleye population (with upper and lower 95% CI) for Escanaba Lake, Wisconsin (1966 - 1974).

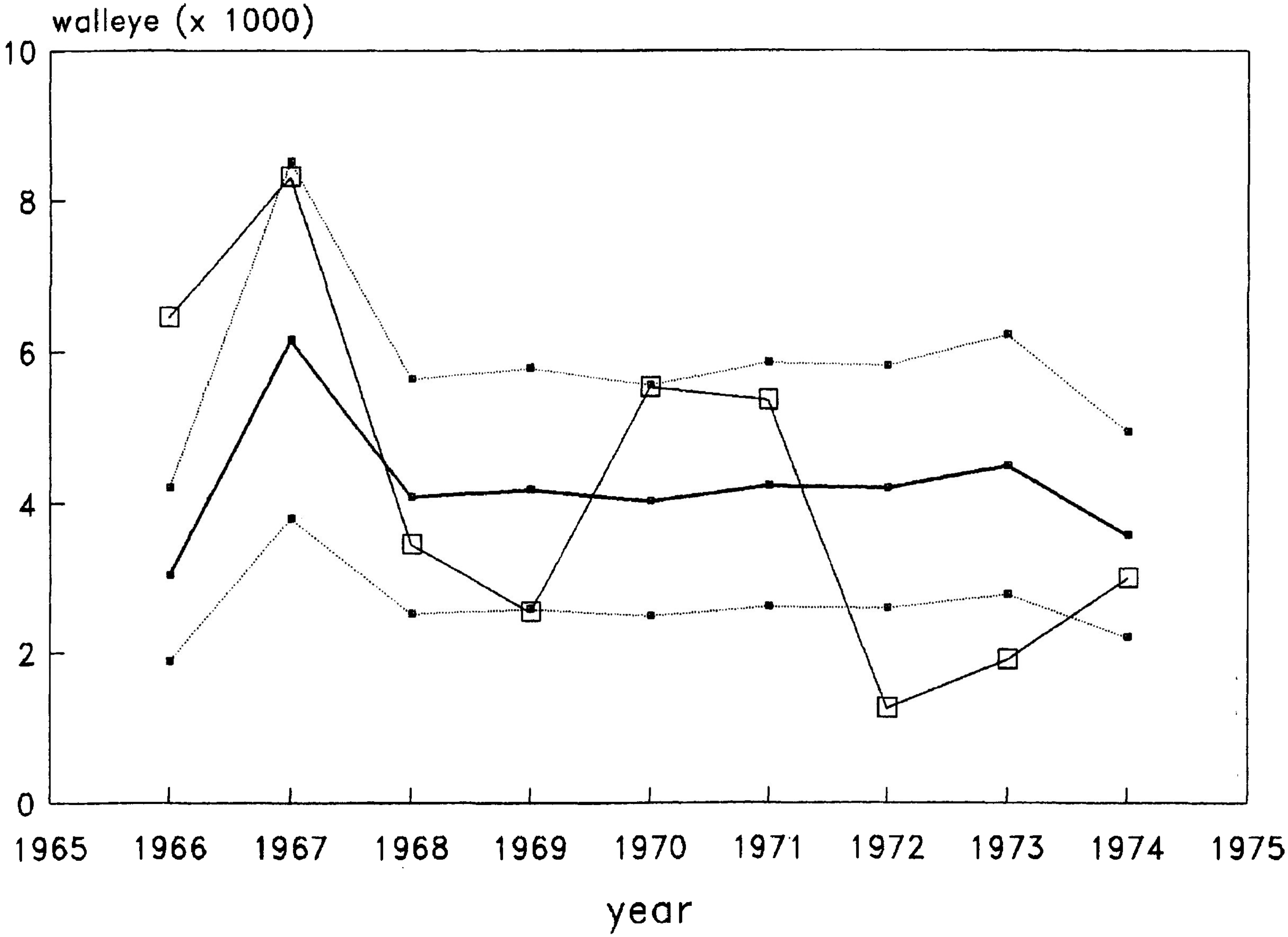
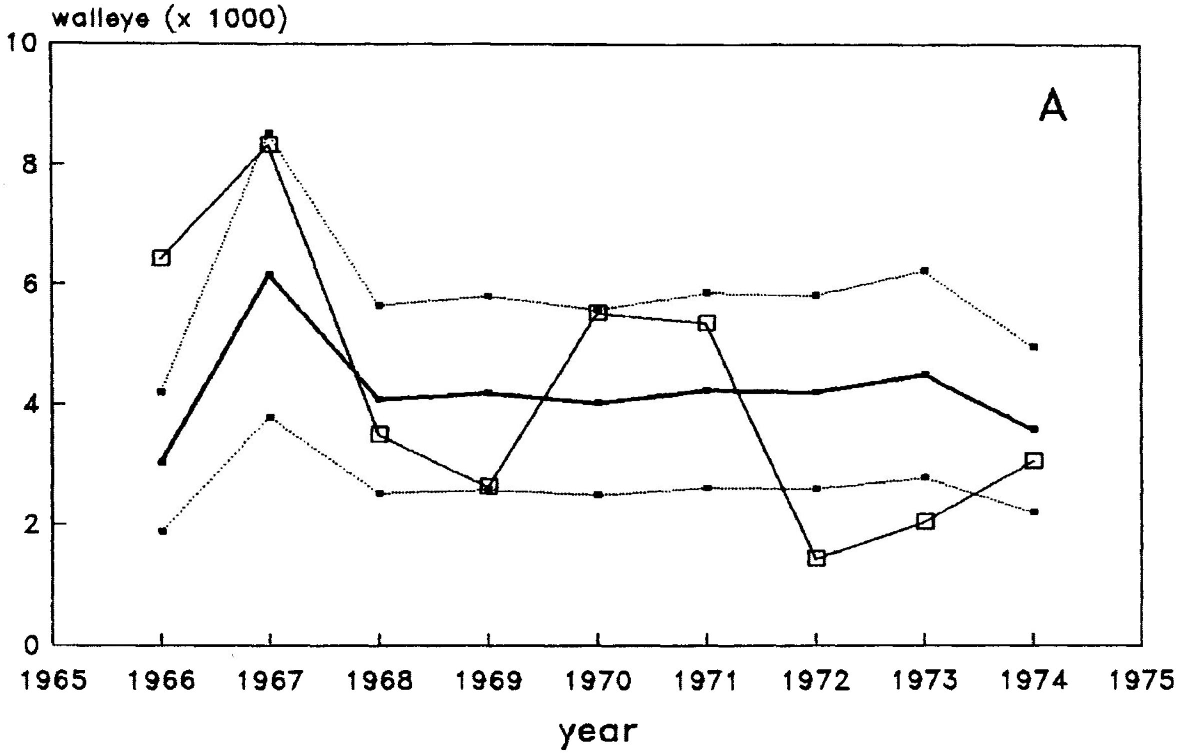

walleye (x 1000)
10
8
6
4
2
0
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
year

Figure 14: A - Predicted walleye abundance from RFZ (square root transform) regression compared with Petersen estimated walleye population (with upper and lower 95% CI) for Escanaba Lake (1966 - 1974). B - Predicted walleye abundance from RFZ (logarithm transform) regression compared with Petersen estimated walleye population (with upper and lower 95% CI) for Escanaba Lake, Wisconsin (1966 - 1974).


walleye (x 1000)
10
8
6
4
2
0
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
year
A

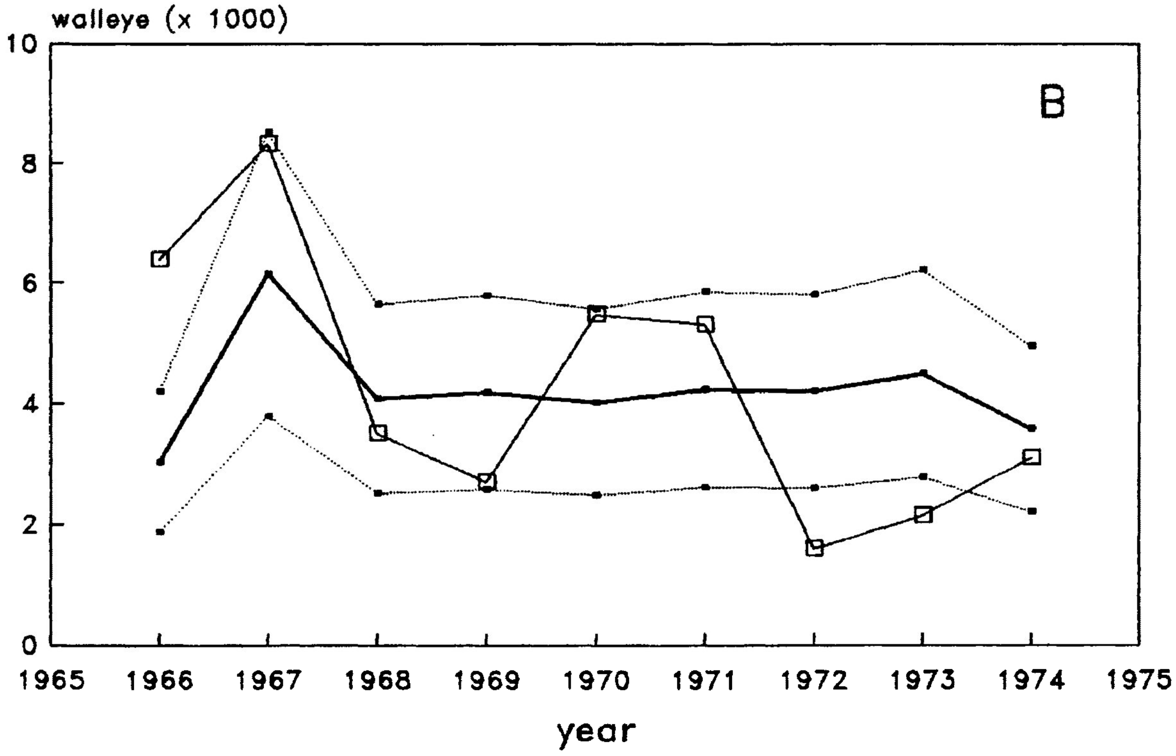

walleye (x 1000)
10
8
6
4
2
0
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
year
B

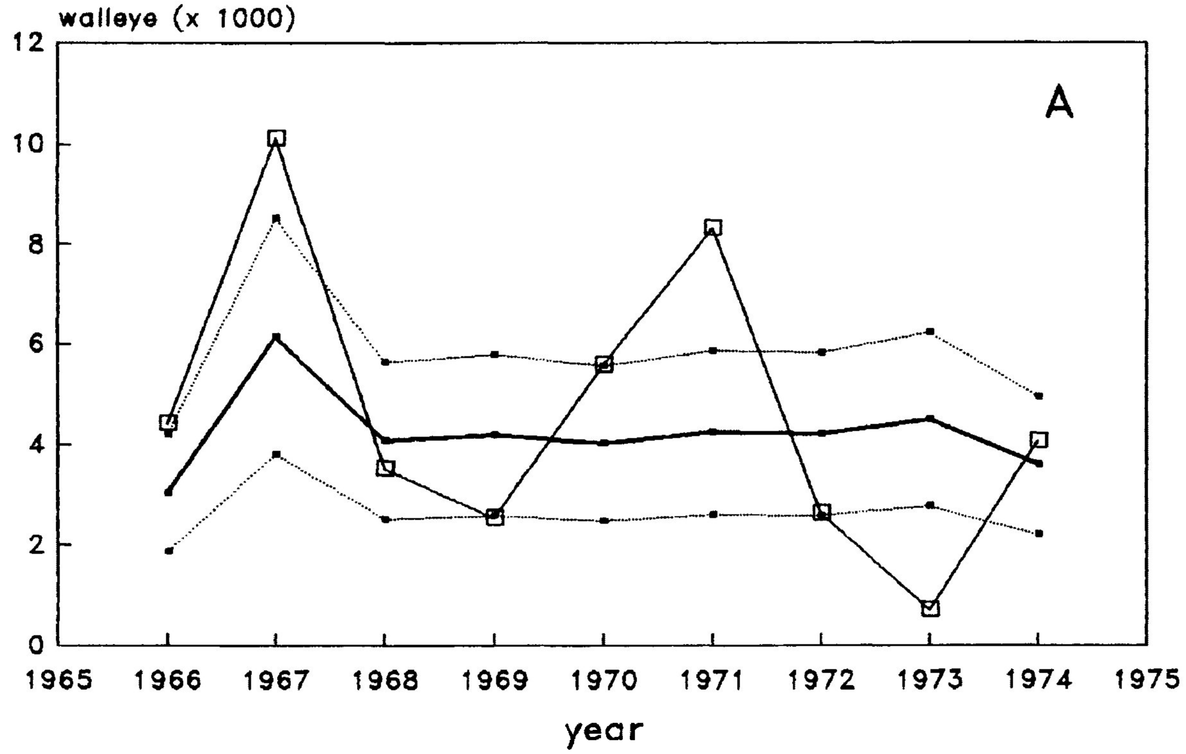
Table 2: Regression coefficients for spring RFZ (April–June) summer RFZ (July–August) and fall RFZ (September – October) values as predictors of walleye population size, Escanaba Lake, Wisconsin.

X	b	m	r2	p	n
RFZ (spring)	27989.357	–327.000	0.646	0.009	9
RFZ (summer)	23565.153	–235.126	0.773	0.002	9
RFZ (fall)	2470.983	37.550	0.007	0.835	9

regression equation – $N = mX + b$
N = walleye population size
n = sample size

Figure 15: A - Predicted walleye abundance from spring RFZ (April - June) regression compared with Petersen estimated walleye population (with upper and lower 95% CI) for Escanaba Lake (1966 - 1974).

B - Predicted walleye abundance from summer RFZ (July - August) regression compared with Petersen estimated walleye population (with upper and lower 95% CI) for Escanaba Lake, Wisconsin (1966 - 1974).


walleye (x 1000)
A
0
2
4
6
8
10
12
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
year

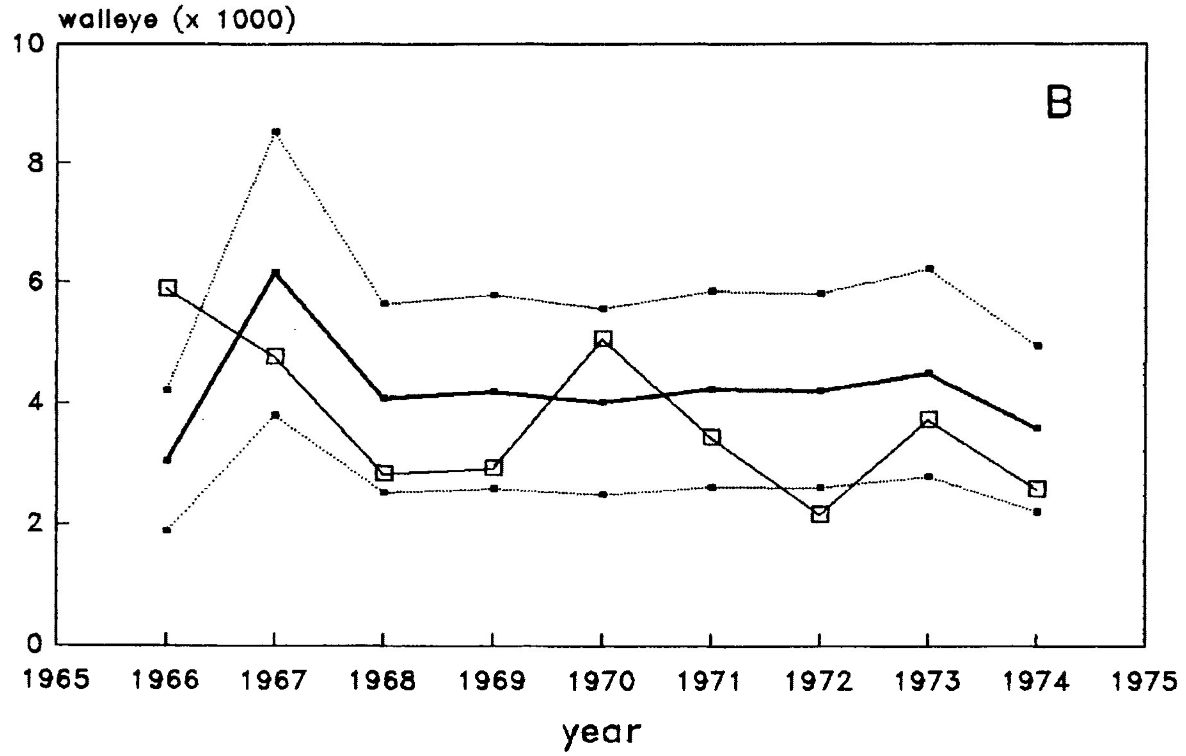

walleye (x 1000)
B
0
2
4
6
8
10
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
year

Figure 16: Predicted walleye abundance from Gini coefficient regression compared with Petersen estimated walleye population (with upper and lower 95% CI) for Escanaba Lake, Wisconsin (1966 - 1974).

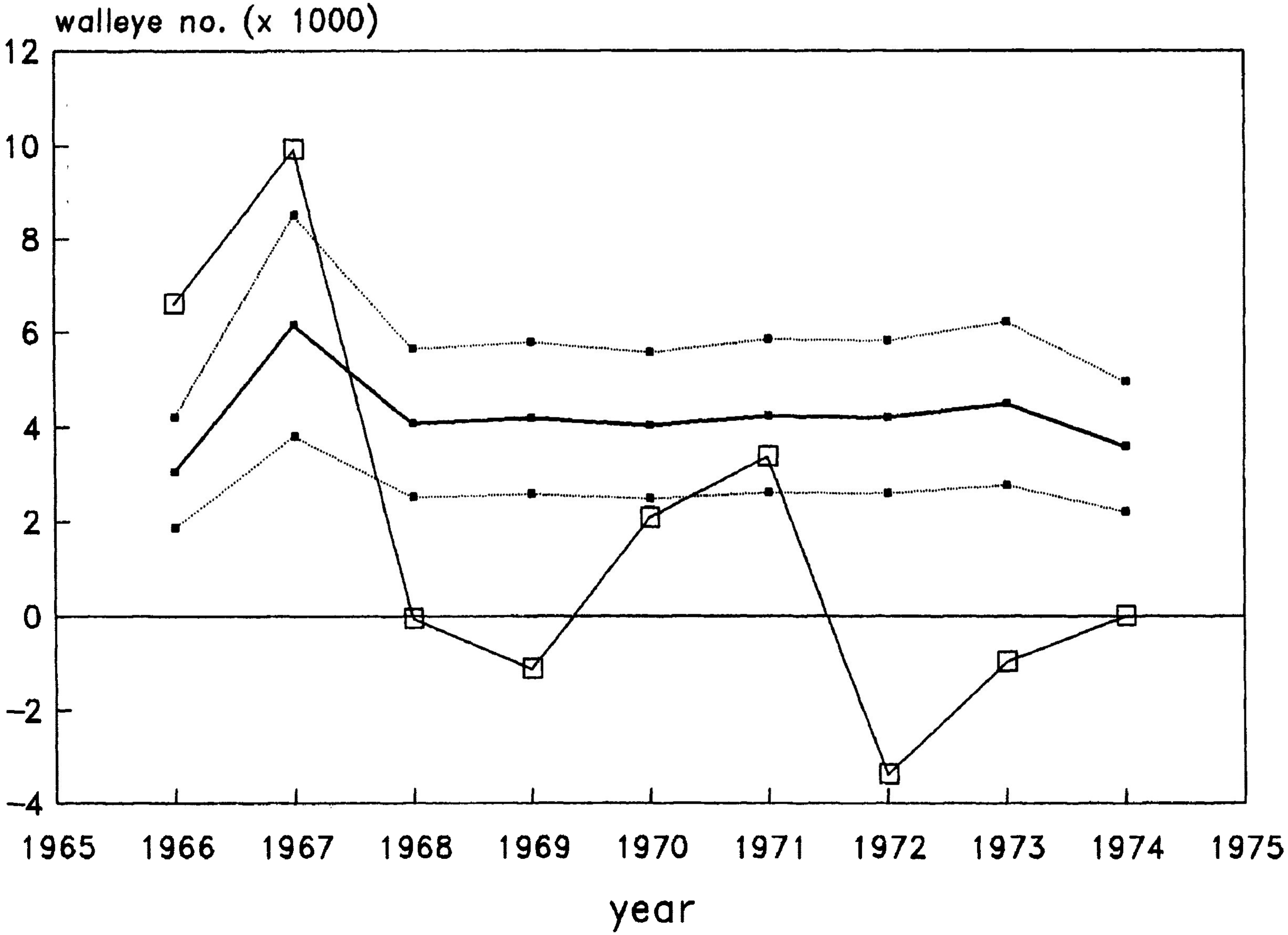

walleye no. (x 1000)
12
10
8
6
4
2
0
-2
-4
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
year

Table 3: Statistical significance of the population predictors in estimating the Petersen population estimate for Escanaba Lake, Wisconsin. (t-test results)

Group	mean	SD	t	Prob.	n
Petersen	4218.444	844.277			9
RFZ	4200.929	2342.658	0.021	0.983	9
RFZ (sqrt)	4240.025	2283.296	0.027	0.979	9
RFZ (ln)	4276.941	2226.422	0.074	0.942	9
Gini	1827.011	4199.583	1.675	0.113	9
Seasonal					
RFZ (spring)	4645.190	2954.596	0.417	0.682	9
RFZ (summer)	3698.050	1272.617	1.022	0.322	9

Discussion

Frequency Distributions of CUE

Distributions of walleye CUE in both Escanaba Lake and the Bay of Quinte were highly skewed with modal values of zero CUE. This catch rate distribution pattern is common to many sport fisheries.

Cryer and Maclean (1991) reported that CUE distributions were always non-normal and highly skewed for a brown trout fishery in New Zealand. This was also found in Pacific salmon sport fisheries (Hilborn 1985), a Florida marine yellowtail snapper fishery (Bannerot and Austin 1983), a bream match test fishery in Britain (Kell 1991) and in walleye, northern pike and smallmouth bass fisheries in Ontario (Morgan and Gordon 1994). Paloheimo and Dickie (1964) and Smith (1990) also reported skewed catch distributions for marine commercial fisheries.

Unsuccessful angling trips ranged from 65 to 85% on Escanaba Lake and from 45 to 65% on the Bay of Quinte. Rupp (1961) reported that unsuccessful angling trips often exceed 60%. In a brown trout fishery, Cryer and Maclean (1991) found that about two-thirds of the anglers were unsuccessful and on any given day up to 75% depart fishless. Morgan and Gordon (1994) reported that on the French River, 52% of the walleye anglers, 40% of the pike anglers and 49% of the smallmouth bass anglers were unsuccessful.

The reasons cited for skewed CUE distributions include low fish abundance (Bannerot and Austin 1983, Smith 1990, Rupp 1961), heterogeneity of fish distribution (Paloheimo and Dickie 1964), bad weather, skill gradients (Rupp 1961) and variation in effort (Hilborn 1985).

Abundance and Catch-Effort Data

Mean CUE

Mean CUE was not linearly related to walleye abundance in Escanaba Lake. Linear regression of mean CUE vs abundance was not significant ($p >> 0.05$) Mean CUE and walleye abundance seem to be related in a curvilinear fashion (Fig. 17). Catch rates initially increase, then plateau at high walleye abundance. Peterman (1980) found that mean CUE reached an asymptote as fish abundance increased. Due to handling time and searching efficiency limitations, only some maximum mean CUE can be realised at high fish abundance (Peterman 1980, Bannerot and Austin 1983).

The equation, $C/f=qN$ (C = catch, f = effort, q = catchability coefficient, N = abundance), is the basis of the assumption that mean CUE is linearly related to N with a slope of q (Peterman and Steer 1981, Bannerot and Austin 1983, Forney 1980). The catchability coefficient q, is assumed to be constant (Peterman and Steer 1981, Bannerot and Austin 1983). Catchability refers to the proportion of the fish stock that is caught with each unit of effort.

In Escanaba Lake, the catchability coefficient q, clearly demonstrates an inverse, non-linear relationship with walleye abundance (Fig. 18). Both Peterman and Steer (1981) and Bannerot and Austin (1983) also demonstrate that q is related to abundance in an inverse, non-linear fashion. This means that anglers catch proportionally more fish at low walleye abundance than at higher abundance.

Density dependent q and asymptotic mean CUE can result from gear saturation (Bannerot and Austin 1983), heterogeneity in fish

Figure 17: Mean CUE versus walleye abundance for Escanaba Lake, Wisconsin (1966 to 1985)

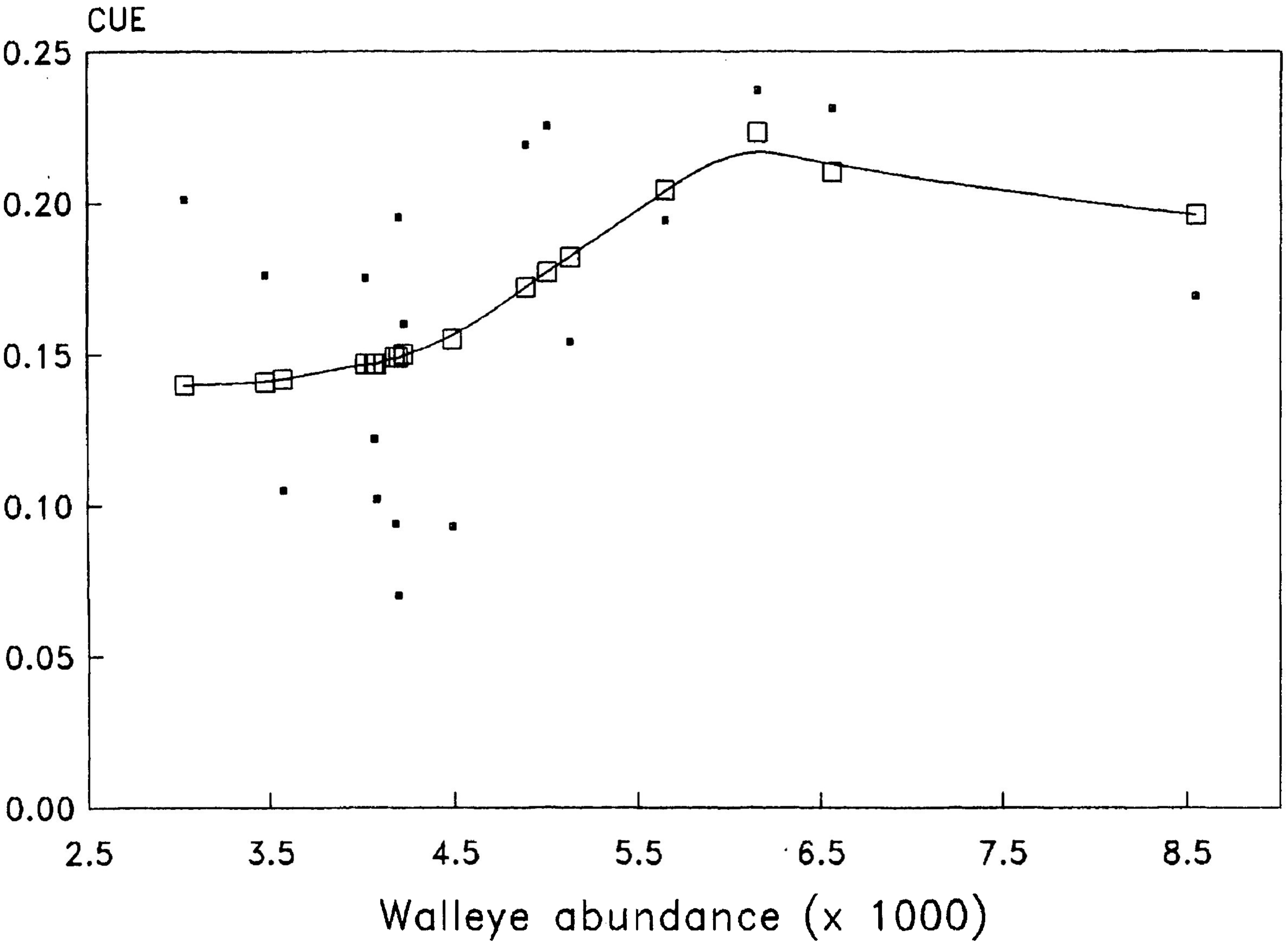
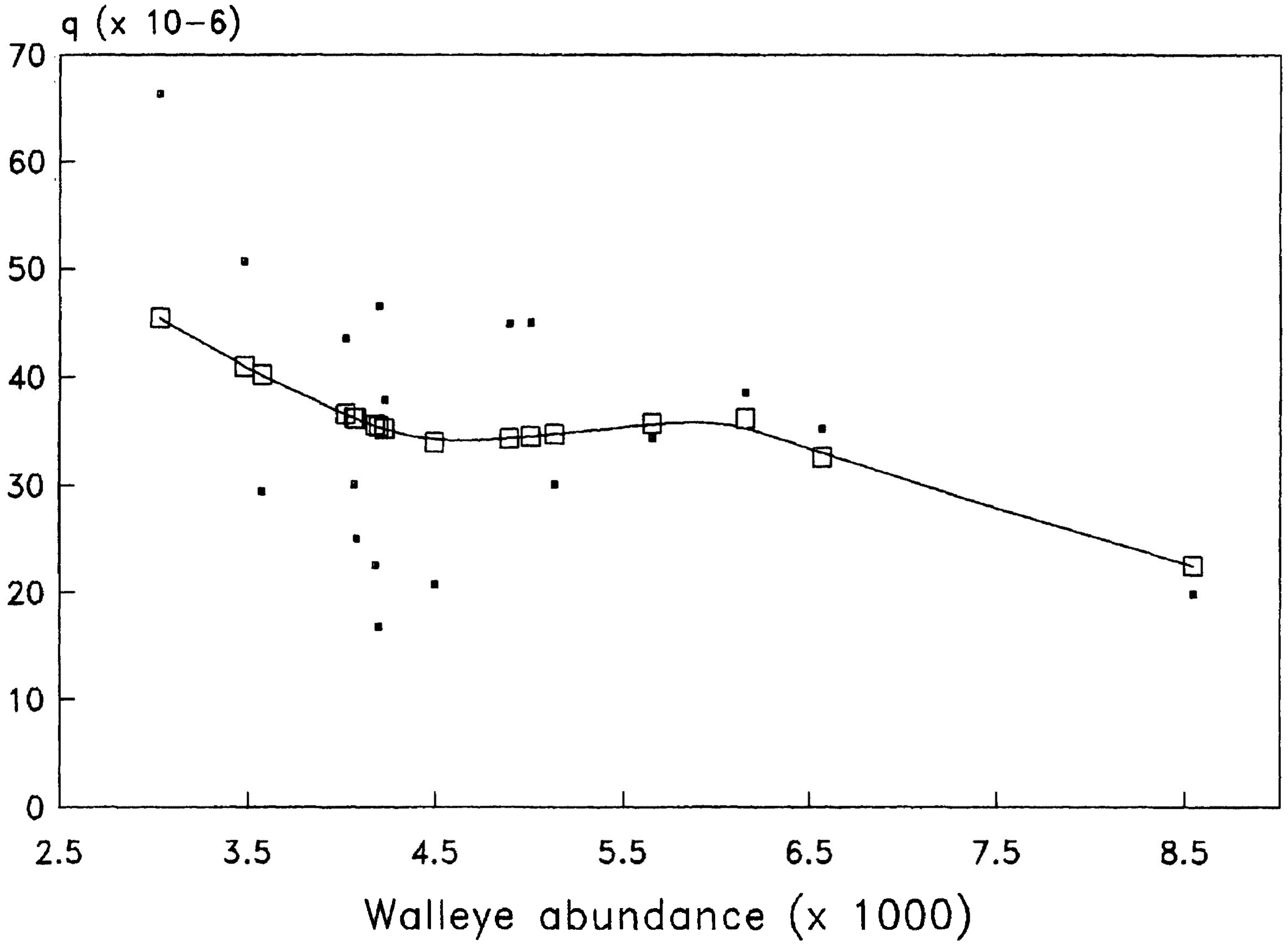

CUE
0.25
0.20
0.15
0.10
0.05
0.00
2.5
3.5
4.5
5.5
6.5
7.5
8.5
Walleye abundance (x 1000)

Figure 18: Catchability coefficient, q versus walleye abundance for Escanaba Lake, Wisconsin (1966 to 1985).


q (x 10-6)
70
60
50
40
30
20
10
0
2.5
3.5
4.5
5.5
6.5
7.5
8.5
Walleye abundance (x 1000)

distribution (Bannerot and Austin 1983, Peterman and Steer 1981, Sampson 1991, Paloheimo and Dickie 1964), and/or non-random search patterns by fishers (Paloheimo and Dickie 1964, Bannerot and Austin 1983).

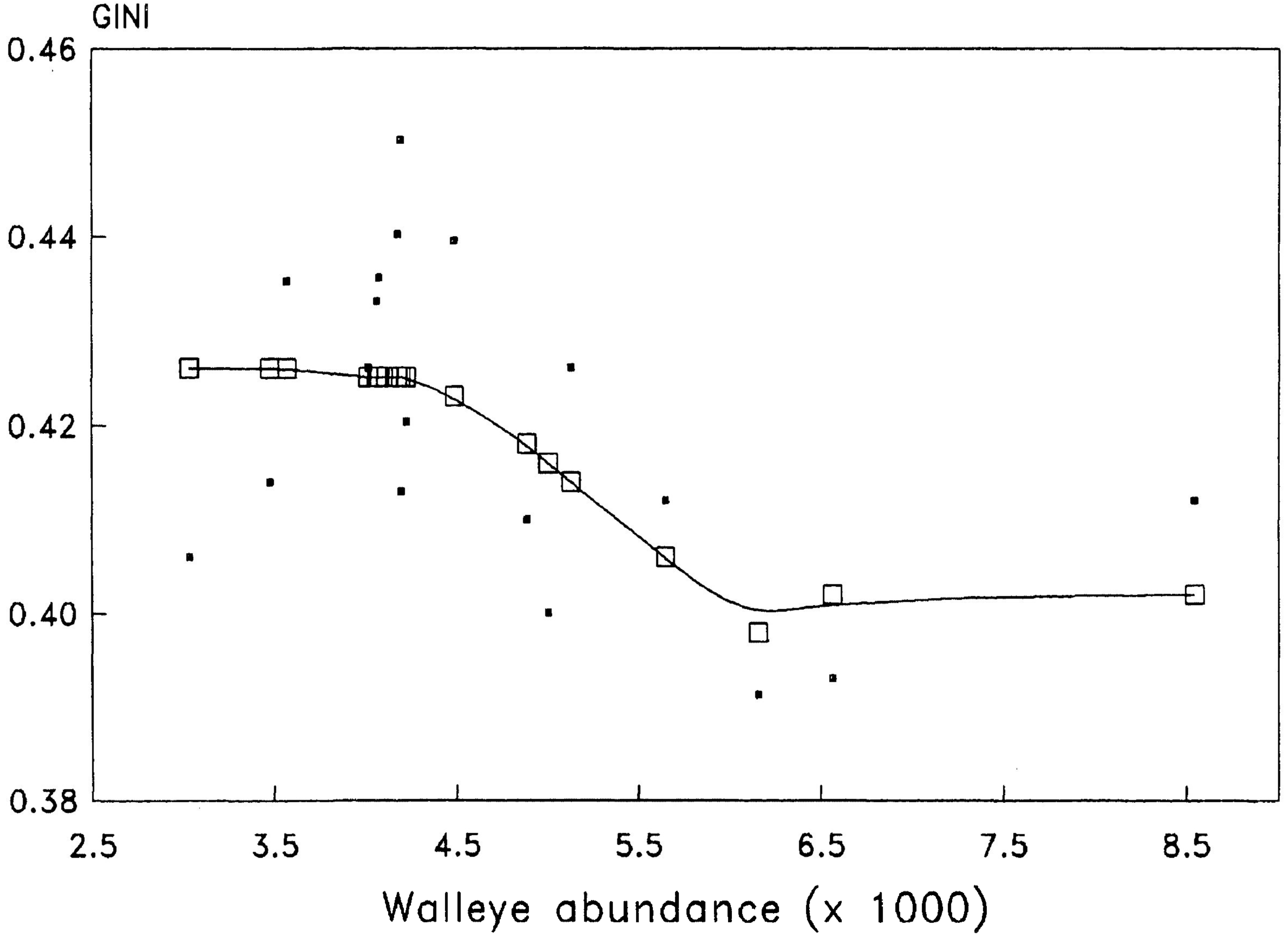
Peterman and Steer (1981) conclude that because mean CUE reaches an asymptote with increasing abundance, change in mean CUE underestimates abundance change. Therefore managers can be dangerously misled by attempting to use mean CUE as an abundance estimator (Peterman and Steer 1981). Many authors have demonstrated the failure of mean CUE to accurately estimate fish abundance (Sampson 1991, Bannerot and Austin 1983, Peterman and Steer 1981, Cryer and Maclean 1991, Hyvarinen and Salojarvi 1991, Beaumont et al 1991, Rose 1992, Shuter et al 1987, Moring 1985, Reid and Momot 1985, Elsey and Thompson 1977, Roff 1983). Despite these facts, mean CUE still is commonly used to assess the status of fish stocks and is the most widely used parameter to assess fish populations (Beaumont et al 1991).

Gini Coefficient

Gini coefficients only recently have been applied in a fisheries context (Smith 1990, Colby et al 1994, Baccante 1995). Weiner and Solbrig (1984) report that the Gini coefficient was a good summary statistic for inequality and can be used to make comparisons within populations over time or among different populations.

However, the present data clearly show that the Gini coefficient could not predict walleye population levels or trends in Escanaba Lake. The Gini coefficient was not linearly related to abundance (Fig 19) when all years were plotted. It did demonstrate a weak but significant relationship for part of the data. The Bay of Quinte Gini coefficient also showed a weak declining trend with walleye abundance.

Figure 19: Gini coefficient versus walleye abundance for Escanaba Lake, Wisconsin (1966 to 1985).


GINI
0.46
0.44
0.42
0.40
0.38
2.5
3.5
4.5
5.5
6.5
7.5
8.5
Walleye abundance (x 1000)

Smith (1990) reported that inequality in catch increases as abundance decreases. In the Oregon coho salmon fishery, Gini coefficients increased over time, indicating greater inequality (Smith 1990). However, these data displayed several trends that were occuring simultaneously including: 1) a decline in stock size, 2) an increase in number of fishers and an increase in technical efficiency, and 3) an increase in stringent management regulations (Smith 1990). Weiner and Solbrig (1984) point out a major problem with Gini coefficients. Namely that two dissimilar distributions can have the same Gini coefficient as long as the ratios under the Lorenz curve are the same. The Lorenz curve graphically represents the degree of inequality in a distribution. Perfect equality results in a diagonal line from the origin to the upper right corner (Weiner and Solbrig 1984). Varying degrees of inequality result in deviations away from the diagonal. The Gini coefficient is the ratio of the area between the diagonal of perfect equality and the curve over the triangular area beneath the diagonal (Weiner and Solbrig 1984).

Relative Frequency of Zero CUE (RFZ)

The RFZ was the only index investigated that was linearly related to walleye abundance in Escanaba Lake. All RFZ regressions were highly significant for both untransformed and transformed values ($p<<0.01$).

Bannerot and Austin (1983) investigated the use of frequency distributions of CUE as an index of fish abundance. Their fishery had right skewed frequency distributions of CUE with the mode at zero CUE. The relative frequency of the mode of the distribution was more sensitive to changes in abundance than the mean of the distribution (mean CUE). Bannerot and Austin (1983) reported that the square root of the relative frequency of zero

CUE was the best index of abundance. This study indicated that the untransformed RFZ was also most highly correlated with walleye abundance in Escanaba Lake.

Skewed frequency distributions of CUE, with the mode at zero CUE, are an inherent property of recreational fisheries (Baccante 1995, Hilborn 1985, Bannerot and Austin 1983, Kell 1991, Cryer and Maclean 1991, Rupp 1961, Morgan and Gordon 1994). Bannerot and Austin (1983) noted that the right skewness of the CUE distribution increases with any decrease in abundance. This is consistent with q being inversely related to abundance and with mean CUE being asymptotically related to abundance (Bannerot and Austin 1983).

Seasonal RFZ

Seasonal RFZ values were less reliable predictors of walleye population trends than the whole season values. Change in walleye distribution, angler skill gradients and environmental conditions could influence both seasonal RFZ values as well as change in walleye abundance. Whole season values probably avoid short term variability in other factors while reflecting change in abundance as the dominant factor influencing RFZ.

Seasonal comparisons of RFZ indicated that angling success changed over the open water season. There was a steady increase in the proportion of unsuccessful anglers as the season progressed. This could be due to change in angler proficiency or changes in walleye distribution and activity. Colby et al (1979) reported that walleye success was greatest in the early months but tapered off in the summer months. Mosindy et al (1987) found greater angling success during the open water season than during the ice fishing season.

Comparison of Population Estimates

Predictions of walleye population level in Escanaba Lake by RFZ and Petersen mark-recapture estimates were significantly similar. Most of the predicted population levels were within 38% (95% confidence interval) of the Petersen estimate. This compares favourably with the results of other comparisons of population estimation techniques. Reid and Momot (1985) compared the performance of Petersen and Schumacher-Eschmeyer population estimation techniques. They found that the two methods produced estimates of the same walleye stock that differed by as much as 27 to 52%. Farman et al (1982) compared a CUE based index to mark-recapture and rotenone population estimation and found differences in the range of 45 to 70%.

Comparison of Methods

All three methods (mean CUE, Gini, RFZ) relating catch-effort data to abundance have the advantage of using data that is routinely collected by natural resource agencies.

Mean CUE and the Gini coefficient were not linearly related to walleye abundance. Only one method, RFZ, proved to be linearly related to walleye abundance in Escanaba Lake.

The Gini coefficient only recently has been applied to fisheries data and with the exception of Smith (1990) has not been used as an index of abundance. This study indicates that the Gini coefficient probably is an invalid indicator of abundance.

Mean CUE is assumed to be linearly related to fish abundance. However, this study indicated that mean CUE is instead related in a curvilinear fashion to abundance. Due to an asymptote in mean CUE as walleye abundance increases (Fig 17), the walleye population could fluctuate by almost 50% and not result in a detectable change in mean CUE. In the light of these findings, the use of mean CUE as an index of abundance for fisheries should be abandoned.

At present, the RFZ index probably is the most accurate method for assessing fish abundance trends from catch-effort data. The observation that skewed distributions of CUE are common to many fisheries suggests that this method has widespread applicability.

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Appendix A: Frequency distribution of CUE for Escanaba Lake, Wisconsin.

Escanaba Lake, Wisconsin
Frequency distributions of catch per unit effort (CUE)
for 1976 to 1985

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
0	2341	3015	3202	2388	2600	2466	2536	2455	4886	2900
.1	11	22	8	2	10	10	6	7	11	7
.2	154	215	168	83	111	102	69	95	83	65
.3	233	231	171	103	151	100	99	114	92	99
.4	230	231	174	135	187	97	109	117	107	115
.5	140	131	118	103	100	58	82	65	73	80
.6	91	80	54	51	62	24	47	58	40	42
.7	99	86	77	72	89	38	48	45	56	68
.8	94	57	68	50	75	37	49	37	37	50
.9	38	28	43	38	53	15	23	34	22	33
1	57	44	64	61	82	25	42	46	48	86
1.1	8	13	6	4	5	2	2	1	3	4
1.2	41	33	42	18	42	16	24	30	25	37
1.3	13	5	14	6	11	6	3	11	12	14
1.4	15	22	21	19	20	12	13	19	20	21
1.5	17	17	15	10	31	9	10	10	24	22
1.6	11	6	9	6	8	3	8	7	12	17
1.7	8	8	6	7	6	5	0	11	14	11
1.8	10	9	8	9	7	4	3	7	6	6
1.9	0	0	1	3	0	0	0	1	2	0
	37	21	57	54	36	14	28	47	87	55
tal	3648	4274	4326	3222	3686	3043	3201	3217	5660	3732

Escanaba Lake, Wisconsin
Frequency distributions of catch per unit effort (CUE)
for 1966 to 1974

966	1967	1968	1969	1970	1971	1972	1973	1974
285	2250	1897	2081	2341	2704	2017	2404	1982
15	9	12	5	6	12	11	15	6
145	141	103	111	193	150	91	88	89
145	161	91	81	160	149	65	97	88
143	206	90	88	165	196	76	76	88
90	129	70	54	86	118	45	41	54
39	59	13	22	59	49	13	30	28
69	66	36	27	33	59	16	44	39
55	71	22	25	35	70	14	23	30
32	27	10	7	14	18	3	20	8
75	83	23	20	35	40	11	17	19
8	2	0	1	2	1	2	0	0
33	37	12	9	9	22	8	7	9
12	15	1	2	9	10	0	3	5
13	26	8	2	5	15	5	6	8
14	17	6	8	8	10	2	6	6
3	8	0	4	7	8	1	2	9
3	13	2	2	4	5	0	5	1
6	14	0	2	3	3	0	3	0
2	6	0	1	2	3	0	0	0
28	60	6	5	9	15	0	8	3
215	3400	2402	2557	3185	3657	2380	2895	2472