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# POPULATION DYNAMICS OF LARGE WALLEYE IN BIG SAND LAKE[1]

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*Abstract.* -- Walleye population parameters in Big Sand Lake, Hubbard County were estimated from 3 years of tagging and creel surveys. Estimated walleye biomass and annual yield were midrange of other North American walleye lakes. Large walleye (≥550 mm) were exploited at lower annual rates than smaller walleye (38.4% for 350 to 549 mm males, 42.7% for 350 to 549 mm females, 13.5% for ≥550 mm males, and 25.2% for ≥550 mm females). Large walleye also had lower annual rates of natural mortality than small walleye (18.9% for 350 to 549 mm males, 14.5% for 350 to 549 mm females, 5.9% for ≥550 mm males, and 8.0% for ≥550 mm females). Voluntary releases of large walleye by anglers contributed to the lower exploitation rates. Although growth of Big Sand Lake walleye was slightly faster than walleye in other Minnesota lakes, the quality size structure was due to sustained growth rates at large sizes and low mortality rates. The experimental regulation allowing harvest of only one walleye greater than 508 mm had little effect on the walleye population in Big Sand Lake.

## Introduction

Numbers of trophy walleye (>3.2 kg) in northwestern Minnesota lakes have declined in the past 20 years (Olson and Cunningham 1989). Increased fishing pressure and improved fishing gear have increased exploitation rates and reduced the numbers of walleye that survive to large sizes. Reduction in trophy walleye angling opportunities may contribute to increasing angler dissatisfaction. The importance of trophy angling opportunities for many Minnesota anglers was illustrated in an angler survey (Leitch and Baltezore 1987) where 48.4% of residents agreed to the statement "I fish so I can catch a trophy" (20.5% disagreed and 31.1% responded with no opinion).

The few lakes that still produce large walleye are becoming increasingly valuable. Big Sand Lake in Hubbard County is one of those lakes and provided the opportunity to study population dynamics of large walleye. Restoration of trophy walleye angling in other waters will be possible only after it is understood how walleye populations in lakes like Big Sand Lake function. The objective of this study was to examine population dynamics of walleye in Big Sand Lake by estimating parameters of growth, mortality, abundance and size-and-age structure.

Harvest of walleye in Big Sand Lake has possibly increased during the past several years,

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in part due to new angling techniques (trolling diving plugs at night) that are efficient in catching walleye suspended over deep water in summer. Public concern that this apparent increase in harvest would eventually reduce the numbers of large walleye in Big Sand Lake prompted implementation of an experimental regulation that allows harvest of only one walleye larger than 508 mm in a daily limit of six fish. The intent of the experimental regulation was to reduce the harvest of large walleye (≥508 mm). A secondary objective of this study was to evaluate effectiveness of this regulation.

## Study Area

Big Sand Lake is a 672 hectare, hardwater (138 ppm total alkalinity) lake with a maximum depth of 41 m. Much of the lake (73%) is deeper than 4.6 m. Shallow water (less than 1.2 m) substrate is composed primarily of sand (60%), gravel (20%), and rock (15%), with the remaining 5% clay. Water quality is good with a secchi depth of 4.9 m (24 July 1989). Submerged vegetation is less abundant than in other area lakes. The lake thermally stratifies in summer and much of the hypolimnion remains oxygenated. The immediate watershed is 90% forested with conifers and mixed hardwoods, and most of the shoreline is developed with approximately 155 homes and cabins and 2 resorts. Fish species present include walleye *Stizostedion vitreum*, northern pike *Esox lucius*, muskellunge *Esox masquinongy*, largemouth bass *Micropterus salmoides*, smallmouth bass *Micropterus dolomieui*, bluegill *Lepomis machrochirus*, pumpkinseed *Lepomis gibbosus*, black crappie *Pomoxis nigromaculatis*, rock bass *Ambloplites rupestris*, white sucker *Catostomus commersoni*, cisco *Coregonus artedii*, yellow perch *Perca flavescens*, yellow bullhead *Ameirus natalis*, Johnny darter *Etheostoma nigrum*, log perch *Percina caprodes*, spottail shiner *Notropis hudsonius*, blacknose shiner *Notropis heterolepis*, and banded killifish *Fundulus diaphanus*. The lake is stocked in even-numbered years with walleye fingerlings intended to supplement natural reproduction.

Big Sand Lake is part of the Mantrap chain of lakes in Hubbard County (Figure 1). A stream connects the lakes from Big Mantrap Lake to Lake Belle Taine. The stream ends at Lake Belle Taine with movement of water to the Crow Wing chain of lakes continuing as groundwater seepage out of Lake Belle Taine.

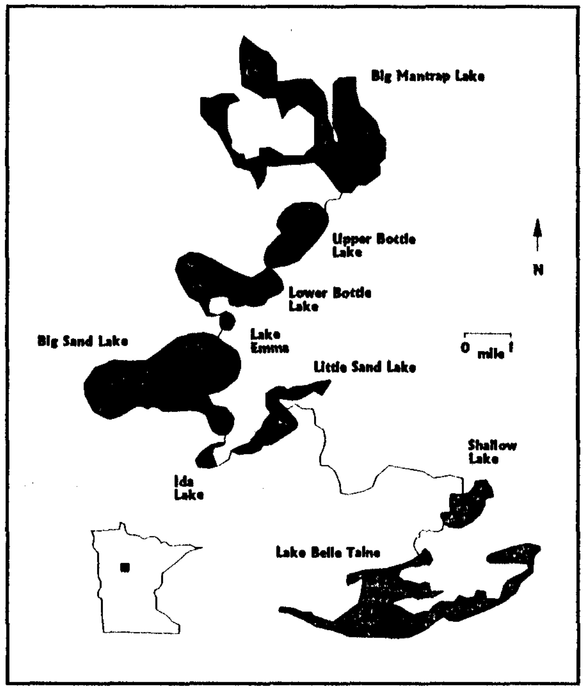


Figure 1. Map of the Mantrap Chain of Lakes in Hubbard County, Minnesota.

Walleye (and northern pike) may not be native to Big Sand Lake and the Mantrap Chain. The isolated nature of the watershed may have prevented movement of walleye and northern pike into the system. Long time residents recollect that the only predator fish species present in the Mantrap Chain in the early 1900s were smallmouth bass, largemouth bass, and muskellunge. Fuller's Tackle Shop Golden Book Fishing Contest Records (Olson and Cunningham 1989) had no contest entries for walleye or northern pike before the 1930s, however, many smallmouth and largemouth bass, and muskellunge were entered during that time.

## Methods

### *Tagging*

Walleye were captured in a pound net at the major inlet to Big Sand Lake during the spring spawning migrations in 1990 from 17

April through 6 May, in 1991 from 23 April through 10 May, and in 1992 from 21 April through 8 May. Trap nets (19 mm bar measure) were also used to capture walleye in the lake. Serially numbered, plastic laminated, disc dangler tags were attached with 0.5 mm stainless steel wire to musculature between the dorsal fins. Total length and sex were recorded for all marked fish. All walleye marked were mature. Walleye were also marked in other lakes in the chain (Belle Taine, Little Sand, Emma, Upper and Lower Bottle) in the spring of 1990 to measure fish movement within the system. A public information program was developed in the area to enhance voluntary tag returns. The program consisted of posting signs at all public access points on the chain, preparing newspaper releases, and notifying all resorts and bait shops of the existence of tagged fish and the importance of returning angler-caught tags.

*Tag Loss Estimation*

Walleye captured during tagging operations in the springs of 1991 and 1992 were examined for tag loss. A lost tag was identified by prominent scarring of flesh around the tag insertion area. Bandow et al. (1993) tagged walleye with similar tags and observed distinct scars on walleye that were known to have lost tags (double tagged). Annual rate of tag loss for the first year ($\tau_1$) was estimated by dividing the number of scarred fish observed in tagging operations in 1991 by the total number of recaptures (including scarred fish) of 1990 tagged fish observed in tagging operations in 1991.

Annual rate of tag loss from data for the second year ($\tau_2$) was estimated by assuming that tag loss rate was constant and that 1990 tagged fish would have had twice the time to lose their tag as 1991 tagged fish (tag losses came from fish tagged in 1990 and 1991). The following equation was solved the for $\tau_2$:

$$L_{92} = 2\,\tau_2\,R^*_{90} + \tau_2\,R^*_{91}\ ;$$

where,

$L_{92}$ = number of scarred fish observed in 1992 tagging operations;

$R^*_{90}$ = number of 1990 tagged fish recaptured during 1992 tagging operations (includes fish with lost tags);

$R^*_{91}$ = number of 1991 tagged fish recaptured during 1992 tagging operations (includes fish with lost tags).

Because the R*'s include fish with lost tags, the number of scarred fish was apportioned to each R* by the following equations:

$$R^*_{90} = R_{90} + L_{92}\,(2R_{90}/(2R_{90} + R_{91}));$$

$$R^*_{91} = R_{91} + L_{92}\,(R_{91}/(2R_{90} + R_{91}));$$

where,

$R_{90}$ = number of 1990 tagged fish recaptured during 1992 tagging operations that retained their tag;

$R_{91}$ = number of 1991 tagged fish recaptured during 1992 tagging operations that retained their tag.

*Population Estimates*

Spring population estimates of walleye in Big Sand Lake were made using the Petersen method, with corrections for migration (modified from Seber 1973; Equation 3.30):

$$N = \frac{(n_1 - \alpha n_1)\,n_2}{m_2} - \hat{a}\,;$$

where,

N = population estimate;

$n_1$ = number of tagged fish extant (includes fish tagged in previous years, observed during tagging operations that year);

$n_2$ = number of fish examined for tags;

$m_2$ = number of recaptures (only recaptures from tagged fish known to be extant in that year were used);

$\alpha$ = estimated proportion of tagged fish lost to migration ($\alpha n_1$ is equal to $-a_m$ of Equation 3.30 of Seber (1973));

$\hat{a}$ = net loss (or gain) of fish to the population from migration.

Variances were estimated using Equation 3.31 of Seber (1973).

The $n_2$ and $m_2$ values were from tagged and untagged fish examined in the creel survey for the first 23 to 26 days of the fishing season (12 May through 7 June in 1990, 11 May through 7 June in 1991, and 9 May through 7 June in 1992). Growth, recruitment, and tag loss were assumed to be negligible during the time periods between tagging and recapture. Population estimates were calculated by size groups: 350 to 449 mm, 450 to 549 mm, and larger than 550 mm.

*Mortality Rate Estimation*

Total annual mortality rates were estimated from the annual exponential decline of angler reported tag returns using the regression method described by Ricker (1975). Walleye tagged in the spring of 1990 were used because they provided the longest series of annual angler reported returns (1990-1993). Tag returns were corrected for tag loss at monthly intervals. Migration of tags out of Big Sand Lake was estimated from tag returns of Big Sand Lake tagged fish caught from other lakes in the chain, which assumed equal survival rates throughout the chain. Although survival rate was not estimated for other lakes in the chain, casual observations indicated that fishing pressure was similar to Big Sand Lake, suggesting similar exploitation rates.

Exploitation rates were estimated from tagged walleye examined in the creel survey. Total number of tagged walleye harvested was estimated as the product of the proportion of tagged walleye observed during the creel survey and estimated total harvest. Only tagged walleye known to be extant for each year (newly tagged fish and previously tagged fish recaptured during that year's tagging operation) were used to estimate exploitation rate for that year. Annual natural mortality rate was estimated as the difference between exploitation rate and total mortality rate.

*Age and Growth*

Annual walleye length increments were estimated from changes in length of fish tagged in 1990 and recaptured during tagging operations in 1991, and from changes in length of fish tagged in 1991 and recaptured during tagging operations in 1992. Dorsal spines (second from the anterior of the fin - cut at the base of the spine) were collected during spring tagging operations in 1992 from at least 10 walleye of each sex per 25 mm group. Age distributions were expanded from subsamples using an age-length key. The Fraser-Lee Method (DISBCAL software, Frie 1982) was used for backcalculating lengths. Von Bertalanffy growth parameters were estimated using nonlinear regression (simplex method, Wilkinson 1992).

*Creel Survey*

Roving creel surveys were conducted in 1990, 1991, and 1992, from opening day of the walleye fishing season through late September (Table 1). The surveys were stratified by 2 week pay periods, day type (weekday or weekend/holiday), and time of day (4 hour time blocks). Shifts within a pay period were first stratified by day type, then assigned by a two stage random sampling procedure (Snedecor and Cochran 1967), with days as primary units and time blocks as secondary units. Four time blocks, 0600-1000, 1000-1400, 1400-1800, and 1800-2200 hours, were used through 28 August in 1990, through 27 August in 1991, and through 25 August in 1992. Three time blocks 0800-1200, 1200-1600, and 1600-2000 hours were used after the same August dates in each

Table 1. Creel survey periods for Big Sand Lake, 1990-1992.

| Period | 1990 | 1991 | 1992 |
|---|---|---|---|
| May | 12 May - 5 June | 11 May - 4 June | 9 May - 2 June |
| June | 6 June - 3 July | 5 June - 2 July | 3 June - 30 June |
| July | 4 July - 31 July | 3 July - 30 July | 1 July - 28 July |
| August | 1 August - 28 August | 31 July - 27 August | 29 July - 25 August |
| September | 29 August - 25 September | 28 August - 24 September | 26 August - 22 September |
| Night | 20 June - 28 August | 5 June - 27 August | 5 June - 25 August |

year. Each time block for each day type was sampled once per pay period. Three instantaneous counts of fishing boats were made during each shift at previously selected, random times from the center of the lake, where the entire surface of the lake could be observed. Estimated fishing pressure (boat-hours), within a day type and time block, was calculated by multiplying mean number of boats on the water in the time block by number of hours in the time block and by number of days of each day type in the pay period. Because only one day of each day type and time block was sampled for a pay period, two pay periods were combined to make variance estimates possible (Cochran 1977). Variance estimates for fishing pressure within a time period (two pay periods) and day type were calculated by ANOVA (two stage sampling, Snedecor and Cochran 1967), calculating a within-time block variance component and a between-time block variance component. A finite population correction was used to adjust the between-block variance component (Cochran 1977). Variances of fishing pressure for an entire fishing season were estimated by summing variances of all strata.

Angler interviews were conducted during each shift between instantaneous pressure counts. Party size, time fished, and numbers of fish caught and released were determined for each boat interviewed. Anglers were also asked to estimate time caught for each walleye and the length of each released walleye. All observed walleye were examined for tags and measured for total length. Weights were obtained from a subsample of fish. The second dorsal spine was collected from walleye in 1992.

A night shift (2200 to 0200 hours) was implemented from 20 June - 28 August 1990, 5 June - 27 August 1991, and 5 June - 25 August 1992. Night fishing during the excluded time periods was considered to be negligible. The night creel survey was access-based (at the one public access) and was stratified only by day type. All anglers returning to the public access during the shift were interviewed, thus direct measures of fishing pressure of boats launched at the public access were attained. Night fishing pressure from boats not using the public access was calculated from the estimated proportion of boats originating from areas other than the public access (determined from angler interviews conducted from 2100 to 2200 hours in the roving portion of the creel survey).

Time fished and numbers of fish caught by each interviewed party was partitioned into the 4 hour time blocks. Harvest and release rates (number of fish/boat hour) for each 4 hour time block in each time period were then calculated with variance estimates for ratio estimators (Cochran 1977). Harvest and released fish estimates were obtained by multiplying the appropriate catch rate by fishing pressure (boat hours) for the time period. Catch rates and fishing pressure in terms of angler hours were calculated by multiplying by mean party size. Catch rates presented in tables were simple ratios of estimated catch per estimated effort.

## Results

*Tag Returns*

A total of 3,579 walleye were tagged in Big Sand Lake during the study (Table 2). Anglers returned 1,253 of the tags over the 4 years of study. The majority (94.4%) were caught in Big Sand Lake (Table 3). Little Sand Lake and Lake Emma produced most of the tagged returns not caught in Big Sand Lake. No tags were returned from Big Mantrap Lake. A dam at the outlet of Big Mantrap Lake prevents upstream movement of fish into the lake. Another 343 walleye were tagged in other Mantrap Chain lakes in the spring of 1990 and returns were primarily from the lake of origin or from lakes nearby in the chain (Table 4).

Table 2. Numbers of walleye tagged in Big Sand Lake in the springs of 1990, 1991, and 1992.

| Year | Previously untagged | Originally tagged in 1990 | Originally tagged in 1991 | Total |
|---|---|---|---|---|
| 1990 | 1,509 | - | - | 1,509 |
| 1991 | 1,182 | 268 | - | 1,450 |
| 1992 | 888 | 135 | 163 | 1,186 |
| TOTAL | 3,579 | 403 | 163 | 4,145 |

Table 3. Location of tags returned by anglers and reported as harvested from walleye tagged in Big Sand Lake in the springs of 1990, 1991, and 1992.

| | | Capture site: | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tagging year | Return year | Upper Bottle | Lower Bottle | Bottle[a] | Emma | Big Sand | Ida | Little Sand | Belle Taine | Unknown | Total | Number tagged |
| 1990 | 1990 | | 3 | 1 | 5 | 272 | 3 | 10 | | 5 | 299 | |
| | 1991 | | | | 2 | 157 | | 2 | | | 161 | |
| | 1992 | 1 | | | | 50 | | 1 | | | 52 | |
| | 1993 | | | | | 31 | | 1 | | | 32 | |
| | Total | 1 | 3 | 1 | 7 | 510 | 3 | 14 | | 5 | 544 | 1,509 |
| 1991 | 1991 | | | | 1 | 356 | 1 | 9 | | | 367 | |
| | 1992 | | | | 1 | 79 | | 6 | 2 | | 88 | |
| | 1993 | | | | | 22 | | | | | 22 | |
| | Total | | | | 2 | 457 | 1 | 15 | 2 | | 477 | 1,182 |
| 1992 | 1992 | | | | 2 | 179 | | 10 | | | 191 | |
| | 1993 | | | | 2 | 37 | | 2 | | | 41 | |
| | Total | | | | 4 | 216 | | 12 | | | 232 | 888 |
| TOTAL | | 1 | 3 | 1 | 13 | 1,183 | 4 | 41 | 2 | 5 | 1,253 | 3,579 |

[a] Angler did not specify Upper or Lower Bottle.

Table 4. Location of tags returned by anglers in 1990, 1991 and 1992 from walleye marked in the spring of 1990 in lakes in the Mantrap Chain other than Big Sand Lake.

| | | Returned from: | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tagging location | Year | Upper Bottle | Lower Bottle | Bottle[a] | Emma | Big Sand | Ida | Little Sand | Belle Taine | Unknown | Total | Number Tagged |
| Inlet to Upper Bottle | 1990 | 17 | | 1 | | | | | | | 18 | |
| | 1991 | 5 | 3 | 1 | | | | | | | 9 | |
| | 1992 | | | | | | | | | | 0 | |
| | 1993 | | | | | | | | | | 0 | |
| | Total | 22 | 3 | 2 | | | | | | | 27 | 65 |
| Inlet to Emma | 1990 | 8 | 5 | 2 | 9 | 5 | 1 | | | | 30 | |
| | 1991 | 2 | | | 1 | 3 | | | | | 6 | |
| | 1992 | | 1 | 1 | | | | | | | 2 | |
| | 1993 | | | | | | | | | | 0 | |
| | Total | 10 | 6 | 3 | 10 | 8 | 1 | | | | 38 | 101 |
| Inlet to Little Sand | 1990 | | | | | 5 | 1 | 6 | | | 12 | |
| | 1991 | | | | | 1 | | 1 | | | 2 | |
| | 1992 | | | | | | | | | | 0 | |
| | 1993 | | | | | | | | | | 0 | |
| | Total | | | | | 6 | 1 | 7 | | | 14 | 32 |
| Outlet of Little Sand | 1990 | | | | | 1 | 1 | 7 | 14 | 1 | 24 | |
| | 1991 | | | | | | | 1 | 7 | | 8 | |
| | 1992 | | | | | | | 4 | 1 | | 5 | |
| | 1993 | | | | | 1 | | | | | 1 | |
| | Total | | | | | 1 | 1 | 12 | 22 | 1 | 38 | 145 |
| TOTAL | | 32 | 9 | 5 | 10 | 16 | 3 | 19 | 22 | 1 | 117 | 343 |

[a]Angler did not specify Upper or Lower Bottle

*Tag Loss*

Twenty fish with tag loss scarring were identified in the spring of 1991. Annual rate of tag loss ($\tau_1$) for 1991 data was estimated at 7.4% (20 scarred fish of the 272 recaptured fish from 1990 tags, which included scarred fish). Forty fish with tag loss scarring were identified in the spring of 1992. Annual rate of tag loss for 1992 data ($\tau_2$) was estimated to be 8.0% ($R_{90}$ = 135 and $R_{91}$ = 163). The mean of the two estimates (weighted by number of scarred fish observed) was 7.8% (instantaneous rate of 0.0812).

*Population Estimates*

The estimated proportion of tagged fish lost to migration ($\alpha$) were estimated for each year from the number of fish tagged in Big Sand Lake and reported from other lakes in the chain, divided by total number of reported recaptures (Table 3): $\alpha_{1990}$=0.0903 (27 out of 299), $\alpha_{1991}$ =0.0300 (11 out of 367), $\alpha_{1992}$=0.0628 (12 out of 191). Lack of population estimates of walleye in other lakes in the Mantrap Chain made an actual estimate of $\hat{a}$ (net loss or gain of fish into Big Sand Lake) impossible. However, because general magnitudes of fish movement in and out of Big Sand Lake were similar, $\hat{a}$ was assumed to be zero (of walleye tagged in other lakes in the chain, 13.1% of 1990 recaptures were caught in Big Sand Lake (Table 4), and of walleye tagged in Big Sand Lake in 1990, 9.0% of 1990 recaptures were caught in other lakes in the chain (Table 3)).

Estimated spring populations of walleye longer than 350 mm in Big Sand Lake declined from 21,508 (32.0 fish/ha, 24.5 kg/ha) in the spring of 1990 to 7,120 (10.6 fish/ha, 13.6 kg/ha) in 1991 and then to 6,779 (10.1 fish/ha, 14.0 kg/ha) in 1992 (Table 5). The decline was a reflection of trends in the smaller size groups (primarily 350-449 mm), while the largest size group (≥550 mm) slightly increased in numbers. The large error associated with the small number of recaptures of the 350 - 449 mm size group in 1990 may have exaggerated the size of the 1990 population and the subsequent decline. The population of walleye ≥450 mm remained relatively stable.

The highest biomass of walleye in Big Sand Lake were in the larger size groups, with the exception of 1990 (Table 5). Biomass of walleye ≥450 mm was relatively stable ranging from 6,969 kg in 1990 to 8,402 kg in 1992. The largest size group of walleye (≥550) experienced an increase in biomass from 3,552 kg in 1990 to 6,058 kg in 1992.

Table 5. Spring population estimates (N) with standard errors (SE), mean weights within a size group, and biomass of walleye in Big Sand Lake for 1990 through 1992 ($n_1$= number of tagged fish extant - includes fish tagged in previous years observed during tagging operations that year, $n_2$= number of fish examined, $m_2$= number of recaptures from tagged fish known to be extant in that year).

| Size group | $n_1$ | $n_2$ | $m_2$ | N | SE | Mean Weight (kg) | Biomass (kg) |
|---|---|---|---|---|---|---|---|
| | | | | 1990 | | | |
| 350-449 mm | 548 | 68 | 2 | 16,950 | 11,811 | 0.56 | 9,492 |
| 450-549 mm | 525 | 58 | 9 | 3,078 | 944 | 1.11 | 3,417 |
| ≥ 550 mm | 428 | 19 | 5 | 1,480 | 568 | 2.40 | 3,552 |
| TOTAL | | | | 21,508 | 11,862 | | 16,461 |
| | | | | 1991 | | | |
| 350-449 mm | 354 | 102 | 13 | 2,694 | 698 | 0.57 | 1,536 |
| 450-549 mm | 664 | 81 | 24 | 2,201 | 378 | 1.10 | 2,421 |
| ≥ 550 mm | 430 | 16 | 3 | 2,225 | 1,158 | 2.33 | 5,184 |
| TOTAL | | | | 7,120 | 1,404 | | 9,141 |
| | | | | 1992 | | | |
| 350-449 mm | 265 | 55 | 8 | 1,707 | 559 | 0.60 | 1,024 |
| 450-549 mm | 550 | 50 | 11 | 2,343 | 625 | 1.09 | 2,344 |
| ≥ 550 mm | 364 | 23 | 3 | 2,729 | 1,475 | 2.22 | 6,058 |
| TOTAL | | | | 6,779 | 1,697 | | 9,426 |

Table 6. Estimated total instantaneous mortality (Z) and annual survival (S) from angler reported returns of walleye tagged in 1990 from Big Sand Lake, returned from 1990 through 1993. Numbers in parenthesis are angler reported returns corrected for tag loss.

| Sex or size group | Number of reported tags 1990 | 1991 | 1992 | 1993 | Z | S |
|---|---|---|---|---|---|---|
| Males | 235 (237.2) | 131 (143.1) | 37 (43.8) | 23 (29.5) | 0.744 | 0.475 |
| Females | 64 (66.5) | 30 (32.7) | 15 (17.8) | 9 (11.5) | 0.587 | 0.556 |
| Both sexes 350-549 mm | 251 (253.3) | 136 (148.5) | 35 (41.4) | 19 (24.3) | 0.831 | 0.436 |
| Both sexes ≥ 550 mm | 47 (47.3) | 25 (27.3) | 17 (20.2) | 13 (16.7) | 0.342 | 0.710 |
| Males 350-549 mm | 221 (223.1) | 116 (126.8) | 29 (34.3) | 17 (20.3) | 0.850 | 0.427 |
| Females 350-549 mm | 30 (30.2) | 20 (21.8) | 6 (7.1) | 2 (2.6) | 0.848 | 0.428 |
| Males ≥ 550 mm | 13 (13.1) | 15 (16.4) | 8 (9.4) | 6 (7.7) | 0.215 | 0.806 |
| Females ≥ 550 mm | 34 (34.3) | 10 (10.9) | 9 (10.6) | 7 (9.0) | 0.404 | 0.668 |

*Mortality*

Large walleye (≥550 mm) survived (Table 6) at a higher mean annual rate (71%) than walleye between 350 and 549 mm (44%). Females survived at higher rates (56%) than males (48%). However, the higher survival rate was probably size related and not sex related. Male walleye actually survived at higher rates than female walleye for fish in the larger size group. Small male and female walleye (350-549 mm) had the lowest mean annual survival rate (43%) and large males (≥550 mm) had the highest mean annual survival rate (81%).

Estimates of annual walleye exploitation rates ranged from 22-49% and averaged 34% (Table 7). Small female walleye consistently experienced the highest exploitation rates (mean 43%), while large male walleye consistently experienced the lowest (mean 14%). Within size groups, exploitation was consistently higher among females. Overall, the highest walleye exploitation rate was recorded in 1991 (49%) and the lowest in 1990 (22%).

Size distributions of tagged walleye harvested by anglers further illustrated the trends in exploitation rates by size (Table 8). Although these rates were minimum estimates because of nonreporting of tags, the trend was for lower exploitation rates of walleye larger than 550 mm for both males and females. Very large female walleye (≥750 mm) had high exploitation rates, although sample sizes were small. Few tags from large (≥550 mm) males were returned by anglers.

Table 7. Estimated exploitation rates for walleye in Big Sand Lake by sex, size and year.

| | 350-549 mm | | ≥ 550 mm | | |
|---|---|---|---|---|---|
| | Males | Females | Males | Females | Total |
| 1990 | 0.258 | 0.289 | 0.081 | 0.153 | 0.222 |
| 1991 | 0.561 | 0.619 | 0.132 | 0.326 | 0.486 |
| 1992 | 0.331 | 0.374 | 0.193 | 0.278 | 0.312 |
| Mean | 0.384 | 0.427 | 0.135 | 0.252 | 0.340 |

Estimates of mean annual natural mortality rates were similar for each sex and lower for large walleye: 18.9% for 350 to 549 mm males, 14.5% for 350 to 549 mm females, 5.9% for ≥550 mm males, and 8.0% for ≥550 mm fe-6males. Instantaneous natural mortality rates were respectively 0.281, 0.215, 0.066, and 0.097.

*Age and Growth*

Tagged female walleye had larger annual length increments than male walleye in both years (Figures 2 and 3). Annual increments of both sexes declined as a function of body size.

Annual length increments of tagged walleye were significantly larger in 1991 than in 1990 (Table 9). A square root transformation of annual increments was an acceptable fit to the data points in Figures 2 and 3 (distributions of residuals were normal and homoscedastic). A

Table 8. Length frequencies of Big Sand Lake walleye tagged in 1990, 1991, and 1992 and harvested by anglers the same year they were tagged and unadjusted exploitation rates (*u*).

| Length (mm) | 1990 Tagged | 1990 Retrnd. | 1990 *u* | 1991 Tagged | 1991 Retrnd. | 1991 *u* | 1992 Tagged | 1992 Retrnd. | 1992 *u* | Total Tagged | Total Retrnd. | Total *u* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Males | | | | | | |
| 300-324 | 2 | 0 | 0.000 | 1 | 0 | 0.000 | 1 | 0 | 0.000 | 4 | 0 | 0.000 |
| 325-349 | 6 | 1 | 0.167 | 1 | 0 | 0.000 | 6 | 0 | 0.000 | 13 | 1 | 0.077 |
| 350-374 | 59 | 11 | 0.186 | 38 | 12 | 0.316 | 11 | 4 | 0.364 | 108 | 27 | 0.250 |
| 375-399 | 154 | 41 | 0.266 | 81 | 29 | 0.358 | 52 | 7 | 0.135 | 287 | 77 | 0.268 |
| 400-424 | 185 | 55 | 0.297 | 119 | 44 | 0.370 | 94 | 19 | 0.202 | 398 | 118 | 0.296 |
| 425-449 | 142 | 33 | 0.232 | 93 | 34 | 0.366 | 103 | 29 | 0.282 | 338 | 96 | 0.284 |
| 450-474 | 120 | 26 | 0.217 | 119 | 47 | 0.395 | 123 | 29 | 0.236 | 362 | 102 | 0.282 |
| 475-499 | 96 | 24 | 0.250 | 80 | 20 | 0.250 | 82 | 15 | 0.183 | 258 | 59 | 0.229 |
| 500-524 | 100 | 18 | 0.180 | 69 | 20 | 0.290 | 68 | 9 | 0.132 | 237 | 47 | 0.198 |
| 525-549 | 101 | 13 | 0.129 | 65 | 10 | 0.154 | 67 | 9 | 0.134 | 233 | 32 | 0.137 |
| 550-574 | 75 | 8 | 0.107 | 55 | 5 | 0.091 | 54 | 3 | 0.056 | 184 | 16 | 0.087 |
| 575-599 | 59 | 3 | 0.051 | 47 | 4 | 0.085 | 47 | 8 | 0.170 | 153 | 15 | 0.098 |
| 600-624 | 29 | 2 | 0.069 | 28 | 2 | 0.071 | 22 | 4 | 0.182 | 79 | 8 | 0.101 |
| 625-649 | 12 | 0 | 0.000 | 10 | 0 | 0.000 | 19 | 0 | 0.000 | 4 | 1 | 0.000 |
| 650-674 | 4 | 0 | 0.000 | 3 | 0 | 0.000 | 3 | 2 | 0.667 | 10 | 2 | 0.200 |
| 675-699 | | | | | | | | | | | | |
| 700-724 | | | | 1 | 0 | 0.000 | | | | 1 | 0 | 0.000 |
| 725-749 | | | | | | | | | | | | |
| 750-774 | | | | | | | | | | | | |
| 775-799 | | | | | | | | | | | | |
| 800-824 | | | | | | | | | | | | |
| TOTAL | 1,144 | 235 | 0.205 | 810 | 227 | 0.280 | 752 | 138 | 0.184 | 2,706 | 600 | 0.222 |
| | | | | | | Females | | | | | | |
| 300-324 | | | | | | | | | | | | |
| 325-349 | | | | | | | | | | | | |
| 350-374 | | | | 1 | 0 | 0.000 | | | | 1 | 0 | 0.000 |
| 375-399 | | | | | | | | | | | | |
| 400-424 | 4 | 2 | 0.500 | 6 | 3 | 0.500 | | | | 10 | 5 | 0.500 |
| 425-449 | 4 | 2 | 0.500 | 16 | 8 | 0.500 | 5 | 4 | 0.800 | 25 | 14 | 0.560 |
| 450-474 | 17 | 4 | 0.235 | 41 | 12 | 0.293 | 21 | 6 | 0.286 | 79 | 22 | 0.278 |
| 475-499 | 24 | 7 | 0.292 | 84 | 29 | 0.345 | 63 | 15 | 0.238 | 171 | 51 | 0.298 |
| 500-524 | 30 | 8 | 0.267 | 119 | 48 | 0.403 | 67 | 16 | 0.239 | 216 | 72 | 0.333 |
| 525-549 | 37 | 7 | 0.189 | 87 | 27 | 0.310 | 59 | 8 | 0.136 | 183 | 42 | 0.230 |
| 550-574 | 27 | 3 | 0.111 | 68 | 21 | 0.309 | 54 | 9 | 0.167 | 149 | 33 | 0.221 |
| 575-599 | 23 | 2 | 0.087 | 36 | 10 | 0.278 | 43 | 5 | 0.116 | 102 | 17 | 0.167 |
| 600-624 | 15 | 3 | 0.200 | 24 | 4 | 0.167 | 25 | 8 | 0.320 | 64 | 15 | 0.234 |
| 625-649 | 33 | 4 | 0.121 | 20 | 2 | 0.100 | 18 | 5 | 0.278 | 71 | 11 | 0.155 |
| 650-674 | 49 | 8 | 0.163 | 36 | 4 | 0.111 | 16 | 1 | 0.063 | 101 | 13 | 0.129 |
| 675-699 | 50 | 6 | 0.120 | 46 | 4 | 0.087 | 23 | 2 | 0.087 | 119 | 12 | 0.101 |
| 700-724 | 19 | 1 | 0.053 | 29 | 3 | 0.103 | 24 | 3 | 0.125 | 72 | 7 | 0.097 |
| 725-749 | 18 | 4 | 0.222 | 13 | 2 | 0.154 | 6 | 0 | 0.000 | 37 | 6 | 0.162 |
| 750-774 | 9 | 1 | 0.111 | 11 | 3 | 0.273 | 6 | 4 | 0.667 | 26 | 8 | 0.308 |
| 775-799 | 6 | 2 | 0.333 | 2 | 1 | 0.500 | 3 | 0 | 0.000 | 11 | 3 | 0.273 |
| 800-824 | | | | 1 | 0 | 0.000 | 1 | 0 | 0.000 | 2 | 0 | 0.000 |
| TOTAL | 365 | 64 | 0.175 | 640 | 181 | 0.283 | 434 | 86 | 0.198 | 1,439 | 331 | 0.230 |

plot of fitted increments illustrated the differences in growth for each sex and year (Figure 4). Walleye grew as much as 10 mm more in length in 1991 than in 1990. The increased growth rate in 1991 may have been a density dependent response related to the smaller population size.

Backcalculated lengths of walleye sampled in 1992 showed similar growth differences by sex (Table 10). Female walleye were more than 100 mm longer (689 mm) than males (581 mm) by age 12. Von Bertalanffy parameters were estimated (from ages 1 to 15 years) to be $L_\infty$=770 mm, K=0.190, and $t_0$=0.039 for

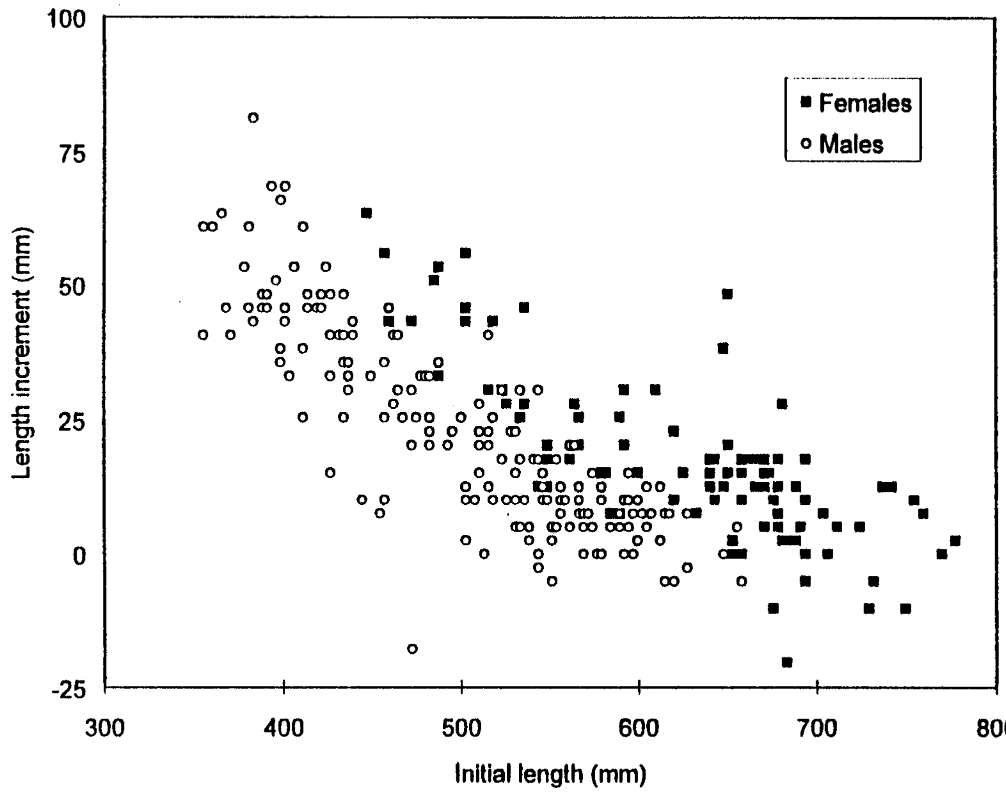


Figure 2. Increment in length of walleye tagged in 1990 and recaptured during tagging operations in 1991.

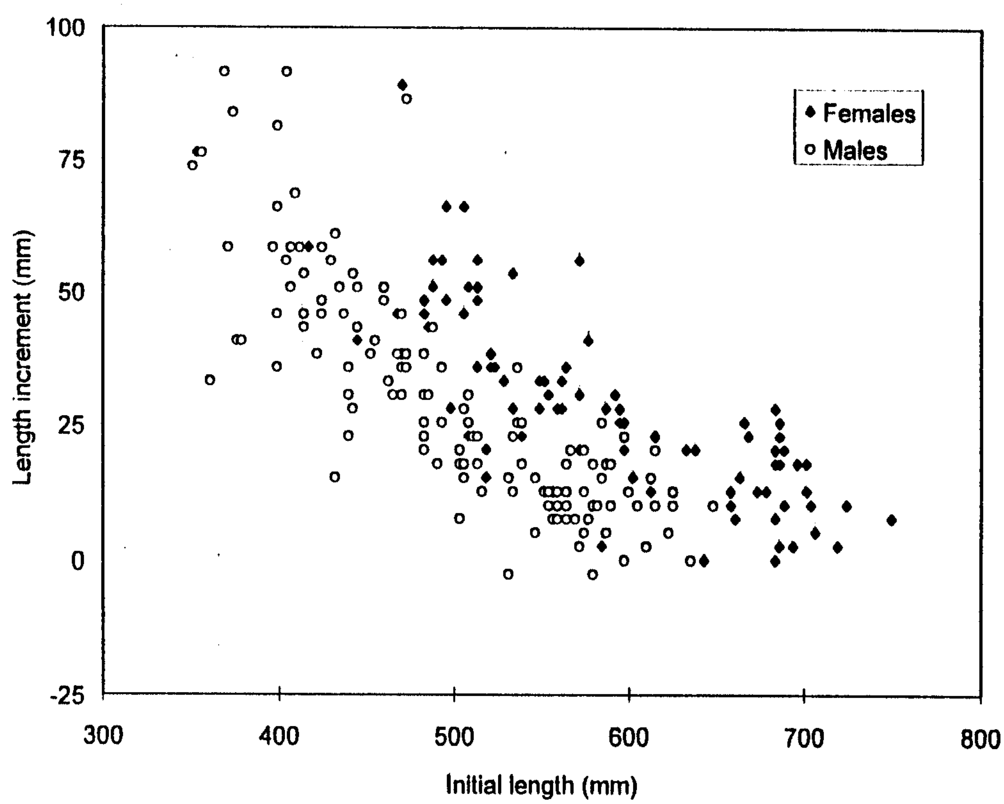


Figure 3. Increment in length for walleye tagged in 1991 and recaptured during tagging operations in 1992.

Table 9. ANCOVA table for the square root of annual length increments of walleye tagged in Big Sand Lake and recaptured during tagging operations one year later for growth years 1990 and 1991 (initial length was the covariate).

| SOURCE | SS | DF | MS | *F*-RATIO | *P* |
|---|---|---|---|---|---|
| SEX | 10.012 | 1 | 10.012 | 190.365 | 0.000 |
| YEAR | 0.936 | 1 | 0.936 | 17.792 | 0.000 |
| SEX*YEAR | 0.150 | 1 | 0.150 | 2.858 | 0.092 |
| INITIAL LENGTH | 45.162 | 1 | 45.162 | 858.676 | 0.000 |
| ERROR | 24.615 | 468 | 0.053 | | |

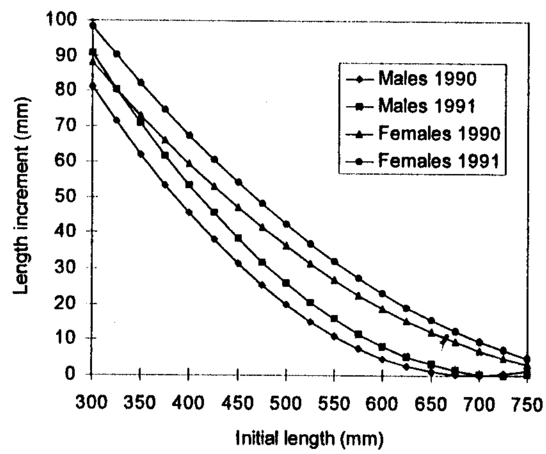


Figure 4. Fitted annual increments of length for walleye in Big Sand Lake, 1990 and 1991.

females and $L_\infty$=627 mm, K=0.234, and $t_0$=0.050 for males.

Many males matured by age 4 (Table 11) at approximately 375 mm. Males at ages 4 through 8 comprised most of the spawning run in 1992 The oldest individuals were 18 years old. Females matured by age 5 or 6 at 475 mm (Table 12), with most fish between 5 and 11 years old and as old as 19 years.

*Creel Survey*

Fishing pressure on Big Sand Lake was consistent during the three years of the study (Table 13) with a mean of 28,002 angler-hours (41.7 angler hours/ha). The majority of pressure (63%) occurred in May and June and steadily declined throughout each summer. September pressure was very light. Night fishing comprised approximately 9% of total angler hours. Most (85%) pressure during all periods was directed at walleye. Nearly one-half (49%) of the anglers originated from the public access, 29% from resorts, and 22% from cabins on the lake.

Estimated annual walleye harvest in Big Sand Lake ranged from 2,206 fish in 1992 to 4,558 in 1991 (Table 14) with a mean of 3,512 (5.2 walleye/ha). Mean annual yield was estimated at 3,432 kg (5.1 kg/ha). Most (65%) walleye were harvested in May and June. Night fishing accounted for 25% of the harvested walleye. Access based anglers harvested the majority of the walleye (71%), while resort guests harvested 23% and cabin owners 6%. Mean size of harvested walleye for the 3 years was 452 mm and 0.98 kg. Night anglers caught (harvested and released) similar sized walleye (mean length of 417 mm) to day anglers (mean length of 442 mm). Most (77%) walleye harvested were smaller than 500 mm (Table 15). Anglers released 74% of walleye less than 350 mm and 39% of walleye larger than 550 mm. Only 8% of walleye between 375 and 524 mm were released. The majority (85%) of walleye releases greater than 508 mm were voluntary (Table 16) and not because of the experimental regulation (14%). Of all walleye caught (harvested and released) over 508 mm, only 4% were released because of the regulation.

Ages 4-7 dominated the walleye harvest in 1992 (Table 17). The oldest fish was 15 years old. Walleye catch rates (harvested and released fish per angler-hour) were highest in the night fishery with a mean of 0.34 and in May with a mean of 0.19 (Table 18). Catches of fish other than walleye, were low (Table 19). Smallmouth bass (mean annual harvest of 0.10 kg/ha) and northern pike (mean annual harvest of 0.19 kg/ha) were the most important predator species other than walleye. Few panfish (crappies, sunfish, rock bass and yellow perch) were harvested. Mean annual harvest was 0.11 kg/ha for all panfish species combined.

Table 10. Backcalculated lengths at age of walleye tagged in Big Sand Lake in the spring of 1992.

| Year-class | Age | *N* | Backcalculated length at age (mm) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Males | | | | | | | | | | |
| 1991 | 1 | 0 | | | | | | | | | | | | | | | | | | |
| 1990 | 2 | 4 | 165 | 254 | | | | | | | | | | | | | | | | |
| 1989 | 3 | 18 | 122 | 228 | 310 | | | | | | | | | | | | | | | |
| 1988 | 4 | 19 | 129 | 215 | 300 | 370 | | | | | | | | | | | | | | |
| 1987 | 5 | 27 | 142 | 237 | 337 | 405 | 451 | | | | | | | | | | | | | |
| 1986 | 6 | 22 | 132 | 215 | 303 | 388 | 445 | 488 | | | | | | | | | | | | |
| 1985 | 7 | 5 | 116 | 187 | 290 | 385 | 444 | 486 | 521 | | | | | | | | | | | |
| 1984 | 8 | 15 | 140 | 215 | 295 | 378 | 439 | 488 | 525 | 553 | | | | | | | | | | |
| 1983 | 9 | 16 | 141 | 208 | 301 | 384 | 434 | 475 | 510 | 537 | 558 | | | | | | | | | |
| 1982 | 10 | 21 | 136 | 212 | 307 | 381 | 433 | 479 | 515 | 547 | 567 | 584 | | | | | | | | |
| 1981 | 11 | 8 | 139 | 211 | 297 | 368 | 430 | 468 | 497 | 522 | 544 | 560 | 578 | | | | | | | |
| 1980 | 12 | 5 | 140 | 209 | 274 | 343 | 394 | 433 | 461 | 493 | 527 | 547 | 567 | 584 | | | | | | |
| 1979 | 13 | 0 | | | | | | | | | | | | | | | | | | |
| 1978 | 14 | 3 | 124 | 205 | 280 | 355 | 404 | 450 | 479 | 508 | 531 | 552 | 571 | 584 | 600 | 613 | | | | |
| 1977 | 15 | 2 | 96 | 159 | 262 | 341 | 391 | 417 | 451 | 481 | 505 | 531 | 552 | 569 | 586 | 603 | 615 | | | |
| 1976 | 16 | 0 | | | | | | | | | | | | | | | | | | |
| 1975 | 17 | 1 | 160 | 229 | 282 | 358 | 419 | 450 | 472 | 495 | 518 | 541 | 564 | 579 | 594 | 610 | 617 | 625 | 640 | |
| Mean | | | 135 | 218 | 306 | 382 | 437 | 476 | 507 | 535 | 553 | 569 | 571 | 581 | 594 | 609 | 616 | 625 | 640 | |
| SE | | | 2.0 | 3.0 | 3.7 | 3.9 | 3.9 | 4.0 | 4.5 | 4.4 | 4.9 | 5.5 | 6.9 | 9.2 | 11.0 | 11.4 | 6.1 | 0.0 | 0.0 | |
| N | | 166 | 166 | 166 | 162 | 144 | 125 | 98 | 76 | 71 | 56 | 40 | 19 | 11 | 6 | 6 | 3 | 1 | 1 | |
| | | | | | | | | | | Females | | | | | | | | | | |
| 1991 | 1 | 0 | | | | | | | | | | | | | | | | | | |
| 1990 | 2 | 0 | | | | | | | | | | | | | | | | | | |
| 1989 | 3 | 5 | 130 | 259 | 361 | | | | | | | | | | | | | | | |
| 1988 | 4 | 21 | 137 | 218 | 316 | 400 | | | | | | | | | | | | | | |
| 1987 | 5 | 27 | 153 | 247 | 342 | 431 | 502 | | | | | | | | | | | | | |
| 1986 | 6 | 18 | 149 | 246 | 336 | 419 | 493 | 546 | | | | | | | | | | | | |
| 1985 | 7 | 8 | 145 | 226 | 343 | 459 | 526 | 564 | 593 | | | | | | | | | | | |
| 1984 | 8 | 15 | 152 | 236 | 332 | 433 | 503 | 551 | 589 | 620 | | | | | | | | | | |
| 1983 | 9 | 15 | 139 | 226 | 313 | 400 | 467 | 532 | 586 | 622 | 650 | | | | | | | | | |
| 1982 | 10 | 17 | 131 | 205 | 309 | 402 | 468 | 529 | 581 | 621 | 649 | 671 | | | | | | | | |
| 1981 | 11 | 5 | 142 | 203 | 281 | 353 | 438 | 501 | 555 | 597 | 629 | 659 | 684 | | | | | | | |
| 1980 | 12 | 6 | 129 | 196 | 263 | 337 | 414 | 480 | 543 | 582 | 622 | 654 | 677 | 697 | | | | | | |
| 1979 | 13 | 3 | 116 | 173 | 237 | 325 | 409 | 471 | 519 | 555 | 598 | 626 | 652 | 679 | 696 | | | | | |
| 1978 | 14 | 4 | 153 | 229 | 309 | 393 | 452 | 499 | 549 | 598 | 634 | 665 | 694 | 720 | 736 | 747 | | | | |
| 1977 | 15 | 6 | 144 | 199 | 271 | 350 | 420 | 470 | 506 | 550 | 587 | 627 | 656 | 679 | 697 | 715 | 726 | | | |
| 1976 | 16 | 1 | 109 | 165 | 227 | 359 | 471 | 519 | 561 | 603 | 638 | 679 | 686 | 728 | 742 | 756 | 770 | 784 | | |
| 1975 | 17 | 1 | 131 | 194 | 236 | 285 | 341 | 418 | 474 | 502 | 530 | 572 | 621 | 649 | 684 | 698 | 712 | 719 | 740 | |
| 1974 | 18 | 1 | 103 | 174 | 238 | 330 | 402 | 458 | 480 | 501 | 522 | 544 | 565 | 600 | 608 | 615 | 622 | 629 | 636 | 643 |
| Mean | | | 142 | 226 | 318 | 405 | 477 | 526 | 568 | 603 | 631 | 653 | 668 | 689 | 703 | 719 | 718 | 711 | 688 | 643 |
| SE | | | 2.0 | 3.0 | 4.1 | 4.7 | 5.2 | 5.3 | 5.0 | 5.1 | 5.6 | 5.9 | 7.9 | 9.0 | 11.7 | 13.2 | 17.5 | 44.9 | 52.2 | 0.0 |
| N | | 153 | 153 | 153 | 153 | 148 | 127 | 100 | 82 | 74 | 59 | 44 | 27 | 22 | 16 | 13 | 9 | 3 | 2 | 1 |

Table 11. Age and length distributions of male walleye tagged in spring 1992 in Big Sand Lake.

| Length group (mm) | Sample size | Subsample size | Number of fish in age group | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 300-324 | 1 | 1 | | | | 1 | | | | | | | | | | | | | | | | |
| 325-349 | 6 | 5 | | | | 1 | 3 | 2 | | | | | | | | | | | | | | |
| 350-374 | 11 | 4 | | | | 5 | 3 | 3 | | | | | | | | | | | | | | |
| 375-399 | 52 | 4 | | | | | 52 | | | | | | | | | | | | | | | |
| 400-424 | 94 | 10 | | | | | 57 | 9 | 19 | 9 | | | | | | | | | | | | |
| 425-449 | 103 | 9 | | | | | 23 | 57 | 23 | | | | | | | | | | | | | |
| 450-474 | 123 | 19 | | | | | 13 | 39 | 52 | 7 | 6 | | 6 | | | | | | | | | |
| 475-499 | 82 | 10 | | | | | 8 | 24 | 25 | 25 | | | | | | | | | | | | |
| 500-524 | 68 | 17 | | | | | | 4 | 32 | 20 | 4 | 8 | | | | | | | | | | |
| 525-549 | 67 | 17 | | | | | | | 8 | 31 | 4 | 12 | 8 | | | | | | | | | |
| 550-574 | 54 | 22 | | | | | | | 3 | 10 | | 7 | 15 | 12 | 5 | | | 2 | | | | |
| 575-599 | 47 | 16 | | | | | | | 3 | | 3 | 6 | 9 | 14 | 9 | 3 | | | | | | |
| 600-624 | 22 | 18 | | | | | | | | | 1 | 5 | 2 | 7 | 2 | 2 | | | 1 | | | |
| 625-649 | 19 | 12 | | | | | | | | | | 1 | 3 | 6 | | 2 | | 3 | 2 | | 2 | |
| 650-674 | 3 | 2 | | | | | | | | | | | | 1 | 2 | | | | | | | |
| 675-699 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 700-724 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 725-749 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 750-774 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 775-799 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 800-824 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| TOTAL | 752 | 166 | 0 | 0 | 0 | 7 | 159 | 138 | 165 | 102 | 18 | 39 | 43 | 40 | 18 | 11 | 0 | 5 | 3 | 0 | 2 | 0 |

Table 12. Age and length distributions of female walleye tagged in spring 1992 in Big Sand Lake.

| Length group (mm) | Sample size | Subsample size | Number of fish in age group | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 300-324 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 325-349 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 350-374 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 375-399 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 400-424 | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| 425-449 | 5 | 5 | | | | | 1 | 3 | | 1 | | | | | | | | | | | | |
| 450-474 | 21 | 7 | | | | | 9 | 6 | 6 | | | | | | | | | | | | | |
| 475-499 | 63 | 8 | | | | | | 55 | 8 | | | | | | | | | | | | | |
| 500-524 | 67 | 8 | | | | | 8 | 42 | 17 | | | | | | | | | | | | | |
| 525-549 | 59 | 9 | | | | | | 26 | 33 | | | | | | | | | | | | | |
| 550-574 | 54 | 12 | | | | | | | 27 | 27 | | | | | | | | | | | | |
| 575-599 | 43 | 16 | | | | | | | 19 | 11 | 5 | 5 | 3 | | | | | | | | | |
| 600-624 | 25 | 16 | | | | | | | 6 | 5 | 6 | 5 | 3 | | | | | | | | | |
| 625-649 | 18 | 10 | | | | | | | | 5 | 2 | 3 | 2 | 2 | 2 | | 2 | | | | | |
| 650-674 | 16 | 12 | | | | | | | | 1 | 1 | 6 | 3 | 3 | | 1 | 2 | | | | | 1 |
| 675-699 | 23 | 16 | | | | | | | | | | 6 | 4 | 10 | | 2 | | | 1 | | | |
| 700-724 | 24 | 20 | | | | | | | | | | | 6 | 7 | 5 | 3 | | 1 | 2 | | | |
| 725-749 | 6 | 5 | | | | | | | | | | | 2 | 1 | | 1 | 1 | | 1 | | | |
| 750-774 | 6 | 3 | | | | | | | | | | | | | | 1 | 1 | 2 | 1 | | 1 | |
| 775-799 | 3 | 2 | | | | | | | | | | | | | | | 1 | | 1 | | | |
| 800-824 | 1 | 1 | | | | | | | | | | | | | | | | 1 | | | | |
| TOTAL | 434 | 153 | 0 | 0 | 0 | 0 | 18 | 132 | 116 | 50 | 14 | 25 | 23 | 23 | 7 | 8 | 5 | 4 | 6 | 0 | 1 | 1 |

Table 13. Angling pressure estimates (angler hours with SE in parenthesis) on Big Sand Lake from 1990 through 1992.

| Month | 1990 | | 1991 | | 1992 | |
|---|---|---|---|---|---|---|
| May | 13,190 | (2,042) | 12,527 | (2,235) | 12,525 | (1,629) |
| June | 4,085 | (754) | 5,364 | (626) | 5,573 | (911) |
| July | 7,005 | (713) | 3,752 | (1,165) | 3,933 | (797) |
| August | 1,842 | (387) | 1,890 | (373) | 2,554 | (332) |
| September | 651 | (211) | 630 | (243) | 662 | (151) |
| Night | 3,864 | (183) | 2,882 | (58) | 1,078 | (121) |
| TOTAL | 30,637 | (2,340) | 27,045 | (2,638) | 26,325 | (2,066) |

Table 14. Estimates of numbers of walleye caught (SE in parenthesis) in Big Sand Lake, 1990 through 1992.

| Month | 1990 | | 1991 | | 1992 | |
|---|---|---|---|---|---|---|
| | | | Harvested | | | |
| May | 1,570 | (278) | 2,344 | (485) | 1,538 | (251) |
| June | 333 | (65) | 715 | (145) | 388 | (96) |
| July | 208 | (73) | 361 | (171) | 164 | (48) |
| August | 226 | (63) | 52 | (32) | 26 | (10) |
| September | 10 | (9) | 12 | (11) | 7 | (6) |
| Night | 1,425 | (77) | 1,074 | (58) | 83 | (14) |
| TOTAL | 3,772 | (311) | 4,558 | (538) | 2,206 | (274) |
| | | | Released | | | |
| May | 433 | (140) | 884 | (277) | 384 | (91) |
| June | 424 | (100) | 93 | (88) | 130 | (43) |
| July | 151 | (64) | 51 | (35) | 54 | (22) |
| August | 35 | (16) | 22 | (13) | 5 | (8) |
| September | 10 | (9) | 12 | (11) | 3 | (4) |
| Night | 578 | (35) | 116 | (12) | 0 | (0) |
| TOTAL | 1,631 | (188) | 1,178 | (294) | 576 | (103) |

Table 15. Length distributions of walleye measured during creel surveys on Big Sand Lake from 1990 through 1992.

| Length (mm) | Harvested 1990 | Harvested 1991 | Harvested 1992 | Harvested Total | Released 1990 | Released 1991 | Released 1992 | Released Total | Percent released |
|---|---|---|---|---|---|---|---|---|---|
| 200-224 | | | | | 7 | 1 | 3 | 11 | 100.0 |
| 225-249 | | | | | 2 | 0 | 2 | 4 | 100.0 |
| 250-274 | | | | | 20 | 3 | 4 | 27 | 100.0 |
| 275-299 | 3 | 5 | 0 | 8 | 6 | 0 | 0 | 6 | 42.9 |
| 300-324 | 4 | 6 | 2 | 12 | 42 | 30 | 3 | 75 | 86.2 |
| 325-349 | 13 | 13 | 2 | 28 | 7 | 2 | 3 | 12 | 30.0 |
| 350-374 | 35 | 36 | 4 | 75 | 17 | 7 | 2 | 26 | 25.7 |
| 375-399 | 32 | 51 | 12 | 95 | 7 | 3 | 0 | 10 | 9.5 |
| 400-424 | 40 | 66 | 28 | 134 | 0 | 5 | 0 | 5 | 3.6 |
| 425-449 | 50 | 35 | 33 | 118 | 8 | 3 | 1 | 12 | 9.2 |
| 450-474 | 43 | 38 | 20 | 101 | 6 | 10 | 3 | 19 | 15.8 |
| 475-499 | 26 | 38 | 19 | 83 | 1 | 0 | 1 | 2 | 2.4 |
| 500-524 | 20 | 32 | 19 | 71 | 3 | 2 | 0 | 5 | 6.6 |
| 525-549 | 13 | 15 | 12 | 40 | 0 | 5 | 3 | 8 | 16.7 |
| 550-574 | 7 | 15 | 10 | 32 | 2 | 6 | 5 | 13 | 28.9 |
| 575-599 | 5 | 6 | 6 | 17 | 4 | 4 | 9 | 17 | 50.0 |
| 600-624 | 3 | 7 | 4 | 14 | 2 | 4 | 4 | 10 | 41.7 |
| 625-649 | 2 | 2 | 4 | 8 | 1 | 1 | 2 | 4 | 33.3 |
| 650-674 | 3 | 0 | 1 | 4 | 2 | 1 | 1 | 4 | 50.0 |
| 675-699 | 0 | 1 | 3 | 4 | 2 | 2 | 1 | 5 | 55.6 |
| 700-724 | 3 | 1 | 0 | 4 | 0 | 1 | 0 | 1 | 20.0 |
| 725-749 | 2 | 0 | 0 | 2 | 1 | 0 | 0 | 1 | 33.3 |
| 750-774 | | | | | 0 | 0 | 1 | 1 | 100.0 |
| 775-799 | 2 | 1 | 0 | 3 | | | | | 0.0 |
| TOTAL | 306 | 368 | 179 | 853 | 140 | 90 | 48 | 278 | 24.6 |

Table 16. Numbers of walleye greater than 508 mm, examined by the creel clerk, that were harvested legally, harvested illegally, released voluntarily, and released because of the special regulation.

| | Year 1990 | Year 1991 | Year 1992 |
|---|---|---|---|
| Harvested legally | 51 | 73 | 49 |
| Harvested illegally | 0 | 1 | 1 |
| Released voluntarily | 12 | 22 | 23 |
| Released because of regulation | 4 | 3 | 2 |

Table 17. Age distribution of walleye harvested from Big Sand Lake and measured during the creel survey in 1992.

| Age | Number |
|---|---|
| 2 | 2 |
| 3 | 8 |
| 4 | 41 |
| 5 | 33 |
| 6 | 21 |
| 7 | 10 |
| 8 | 3 |
| 9 | 4 |
| 10 | 3 |
| 11 | 1 |
| 12 | 1 |
| 13 | |
| 14 | 1 |
| 15 | 1 |
| TOTAL | 129 |

Table 18. Estimated walleye catch rates (number per hour) in Big Sand Lake, 1990 through 1992.

| Month | 1990 | 1991 | 1992 |
|---|---|---|---|
| | | Harvested | |
| May | 0.119 | 0.187 | 0.123 |
| June | 0.082 | 0.133 | 0.070 |
| July | 0.030 | 0.096 | 0.042 |
| August | 0.123 | 0.028 | 0.010 |
| September | 0.015 | 0.019 | 0.011 |
| Night | 0.369 | 0.373 | 0.077 |
| TOTAL | 0.123 | 0.169 | 0.084 |
| | | Released | |
| May | 0.033 | 0.071 | 0.031 |
| June | 0.104 | 0.017 | 0.023 |
| July | 0.022 | 0.014 | 0.014 |
| August | 0.019 | 0.012 | 0.002 |
| September | 0.015 | 0.019 | 0.005 |
| Night | 0.150 | 0.040 | 0.000 |
| TOTAL | 0.053 | 0.044 | 0.022 |

## Discussion

The quality size structure of walleye in Big Sand Lake was the result of low mortality rates of large fish and sustained growth rates. Exploitation rates of large walleye (≥550 mm) were considerably lower than for smaller walleye. Although releases of large walleye partially explain the lower exploitation rates, large walleye were less vulnerable to anglers. Serns and Kempinger (1981) and Payer et al. (1987) also found larger walleye to be less vulnerable to angling. Compared to exploitation rates estimated for other populations of walleye in Minnesota, Big Sand Lake exploitation rates were midrange (Table 20). The majority of the exploitation pressure in Big Sand Lake was centered on smaller walleye, similar to many of the traditional walleye lakes in Minnesota. Natural mortality rates of large walleye were also lower than for small walleye. Natural mortality rates for walleye in Big Sand Lake were within the 5-30% range reported by Ney (1978). Natural mortality rates of large walleye were similar to the 4.8% estimated by Olson (1957). Mean biomass (17.4 kg/ha) and annual harvest (5.1 kg/ha) were midrange of North American walleye biomasses and harvests (Carlander 1977). Growth rates of Big Sand Lake walleye were faster at early ages than those in some of Minnesota's important walleye waters (Table 21). Big Sand Lake walleye maintained or slightly increased their growth rate advantage at larger sizes and older ages then other walleye populations.

Good habitat and abundant forage in Big Sand Lake may be the reason for the lower exploitation rates and sustained growth of large walleye. An abundance of deep water, with an oxygenated hypolimnion, provides habitat for a

Table 19. Estimates of fish other than walleye caught in Big Sand Lake, 1990 through 1992. Mean weight (kg) is of harvested fish.

| Species | 1990 Harvested | 1990 Released | 1990 Mean weight | 1991 Harvested | 1991 Released | 1991 Mean weight | 1992 Harvested | 1992 Released | 1992 Mean weight |
|---|---|---|---|---|---|---|---|---|---|
| Smallmouth bass | 195 | 299 | 0.75 | 59 | 342 | 0.63 | 34 | 172 | 0.60 |
| Largemouth bass | 0 | 17 | - | 0 | 28 | - | 0 | 4 | - |
| Northern pike | 139 | 152 | 1.02 | 56 | 99 | 2.19 | 31 | 20 | 3.57 |
| Muskellunge | 0 | 10 | - | 0 | 8 | - | 0 | 0 | - |
| Rock bass | 87 | 495 | 0.29 | 94 | 356 | 0.31 | 19 | 66 | 0.25 |
| Black crappie | 14 | 20 | 0.74 | 0 | 0 | - | 67 | 0 | 0.42 |
| Sunfish | 77 | 97 | 0.18 | 283 | 25 | 0.28 | 24 | 82 | 0.16 |
| Yellow perch | 455 | NE | 0.08 | 289 | NE | 0.15 | 17 | NE | 0.13 |
| White sucker | 22 | 44 | NE | 0 | 0 | - | 0 | 0 | - |

NE = not estimated

Table 20. Unadjusted annual rates of exploitation based on voluntary reports of tagged walleye in Minnesota.

| Lake | Year(s) | Source | Tag | Size, sex | Exploitation Rate |
|---|---|---|---|---|---|
| Vermillion | 1940 | Carlander 1941 | jaw tags | mature fish | 0.050 |
| St. Louis River Estuary | 1980-82 | Osborn et al. 1991 | T-bar anchor | mature fish | 0.081 |
| Sallie | 1954 | Olson 1955 | jaw and opercle tags | mature fish | 0.093 |
| Winnibigoshish | 1937-39 | Stoudt and Eddy 1939 | jaw tags | mature fish | 0.102 |
| Lake of the Woods (MN waters) | 1982 | Payer et al. 1987 | disc dangler | ≥ 279 mm males, ≥ 330 mm females | 0.137[a] |
| Cass, Andrusia, Big Wolf | 1971-75 | Strand 1980 | disc dangler | mature females | 0.158 |
| Big Sand | 1990-92 | this study | disc dangler | mature females | 0.222 |
| Big Sand | 1990-92 | this study | disc dangler | mature males | 0.230 |
| Winnibigoshish | 1975-1977 | Osborn et al. 1985 | T-bar anchor and disc dangler | mature males | 0.231 |
| Cass, Andrusia, Big Wolf | 1971-75 | Strand 1980 | disc dangler | mature males | 0.260 |
| Winnibigoshish | 1975-1977 | Osborn et al. 1985 | T-bar anchor and disc dangler | mature females | 0.261 |
| Many Point | 1955-57 | Olson 1957 | fin clip | ≥ 356 mm | 0.269 |
| Otter Tail | 1983 | Schreiner 1987 | disc dangler | mature fish | 0.279 |

[a] sport fishing only

Table 21. Backcalculated lengths (mm) at age of walleye in Minnesota.

| Age | Lake of the Woods[a] 1983-84 | Cass[b] 1990 | Leech[c] 1985-90 | Winnibigoshish[d] 1990 | Mille Lacs[e] 1983-90 | Kabetogoma[f] 1990 | Big Sand[g] 1992 |
|---|---|---|---|---|---|---|---|
| | | | | Males | | | |
| 1 | 140 | 147 | 155 | 127 | 137 | 132 | 135 |
| 2 | 213 | 229 | 239 | 216 | 216 | 213 | 218 |
| 3 | 284 | 295 | 307 | 292 | 282 | 277 | 305 |
| 4 | 335 | 351 | 356 | 348 | 343 | 351 | 381 |
| 5 | 378 | 381 | 391 | 399 | 394 | 411 | 437 |
| 6 | 411 | 427 | 419 | 439 | 429 | 450 | 478 |
| 7 | 432 | 450 | 439 | 488 | 460 | 465 | 508 |
| 8 | 452 | 465 | 455 | 536 | 485 | 493 | 536 |
| 9 | 500 | | | | 498 | 508 | 554 |
| 10 | 508 | | | | 526 | 521 | 569 |
| 11 | | | | | | 531 | 572 |
| 12 | | | | | | | 582 |
| | | | | Females | | | |
| 1 | 145 | 147 | 157 | 132 | 140 | 132 | 142 |
| 2 | 218 | 226 | 244 | 221 | 221 | 226 | 226 |
| 3 | 290 | 297 | 318 | 307 | 290 | 302 | 318 |
| 4 | 343 | 358 | 373 | 373 | 358 | 368 | 406 |
| 5 | 389 | 409 | 422 | 414 | 424 | 434 | 478 |
| 6 | 429 | 457 | 457 | 457 | 475 | 480 | 526 |
| 7 | 455 | 498 | 485 | 645 | 518 | 531 | 569 |
| 8 | 508 | 544 | 490 | | 544 | 564 | 605 |
| 9 | 554 | 569 | | | 574 | 594 | 630 |
| 10 | 538 | 599 | | | 602 | 612 | 653 |
| 11 | 602 | 627 | | | | 625 | 668 |
| 12 | 622 | | | | | 648 | 688 |
| 13 | 632 | | | | | | 704 |
| 14 | 645 | | | | | | 719 |

[a] Payer et al. 1987
[b] Boe 1991
[c] Haukos 1991
[d] Albert 1991
[e] Bruesewitz 1991
[f] Eibler 1991
[g] This study

large population of small cisco that, along with an abundant yellow perch population, provide large walleye with a good forage base. In addition, the deep water may provide a refuge for larger walleye and the high water clarity may make them more difficult to catch. Although the night fishery that developed on Big Sand Lake provided a way to catch these deep water walleye in summer, it contributed only 25% of total harvest, which did not suggest an excessive level of harvest. Also, night anglers did not catch larger walleye than day anglers.

The experimental regulation of one walleye over 508 mm had little effect on the Big Sand Lake walleye population. Only 4% of walleye caught larger than 508 mm were released because of the regulation. Voluntary releases of walleye larger than 508 mm were considerably higher than releases because of the regulation. Although the creel survey used primarily incomplete interviews (regulation releases would have been higher in completed bags), it is doubtful that regulation releases were significant. A 1992 creel survey of Little McDonald Lake (Tables 22-24) in Otter Tail County (a lake similar to Big Sand Lake in morphology, chemistry and reputation for large walleye), with a design identical to the Big Sand Lake creel survey, estimated a voluntary release rate of 25.0% for walleye larger than 508 mm, which is similar to

Table 22. Estimates of angling pressure, walleye catch and catch rates from Little McDonald Lake, Otter Tail County in 1992 (SE in parenthesis).

| Month | Angler hours | Numbers of fish | | Catch per hour | |
|---|---|---|---|---|---|
| | | Harvested | Released | Harvested | Released |
| May | 1,204 (355) | 48 (27) | 14 (11) | 0.040 | 0.012 |
| June | 2,538 (477) | 102 (34) | 30 (15) | 0.040 | 0.012 |
| July | 4,087 (499) | 165 (44) | 44 (21) | 0.040 | 0.011 |
| August | 2,313 (434) | 218 (59) | 174 (57) | 0.094 | 0.075 |
| September | 1,600 (279) | 44 (22) | 13 (10) | 0.028 | 0.008 |
| Night | 636 (45) | 90 (12) | 63 (8) | 0.142 | 0.099 |
| TOTAL | 12,378 (933) | 667 (89) | 338 (65) | 0.054 | 0.027 |

the Big Sand Lake. Size limits were not in effect on Little McDonald Lake, which suggests that the voluntary release of large walleye was occurring independently from any indirect influence of the one over 508 mm regulation.

Although exploitation rates of small walleye were high in some years (greater than 50% in 1991), the existing size structure of walleye in Big Sand Lake appears to be sustainable. Walleye abundance in Big Sand Lake declined over the study period, but the decline was in the smallest (350-449 mm) size group. The population of larger walleye was relatively stable. Apparently, angling impacted the population of smaller walleye more than the larger walleye. Also, length and age distributions of walleye collected during the 1988 spawning run by the Park Rapids Management Area from an identical trap at the inlet to Big Sand Lake (Tables 25,26) suggested that no significant changes in the size structure occurred from 1988 through 1992. Records from the Fuller's Tackle Shop Golden Book Fishing Contest (Olson and Cunningham 1987) indicate that the population of trophy walleye in Big Sand Lake, is on a upward trend, after a large peak of entries in the 1940s and a sharp decline in the 1950s (Figure 5).

Although the existing population structure appears to be sustainable, evidence exists that the size structure of Big Sand Lake walleye was better in the past. Of 16 spawning runs in Minnesota sampled from 1939 through 1942, Big Sand Lake had the largest sizes of walleye (Carlander 1942). In 1942, mean length of Big Sand Lake walleye was 546 mm for males (compared to 462 mm in 1990-1992) and 627 mm for females (compared to 556 mm in 1990-1992). Although actual length distributions were not presented, Carlander (1942) calculated a statistic where 90% of males were larger than 452 mm (compared to only 56% in 1990-1992) and 90% of females were larger than 592 mm (compared to only 38% in 1990-1992).

## Management Implications

Although the existing walleye size structure in Big Sand Lake appears to be sustainable, historical evidence (Carlander 1942) and the occurrence of high exploitation rates in some years, suggest that it could be improved. A regulation that protects walleye through the size range with the highest exploitation rates (375-525 mm) appears to have the best chance of increasing numbers of large walleye. The current one over 508 mm experimental regulation had little effect on the population of walleye in Big Sand Lake and should be discontinued.

Table 23. Length distributions of walleye measured during the creel survey on Little McDonald Lake in 1992.

| Length (mm) | Harvested | Released |
|---|---|---|
| 200-224 | | 1 |
| 225-249 | | 1 |
| 250-274 | | 2 |
| 275-299 | 3 | 7 |
| 300-324 | 2 | 14 |
| 325-349 | 10 | 5 |
| 350-374 | 9 | 2 |
| 375-399 | 10 | |
| 400-424 | 5 | 1 |
| 425-449 | 15 | |
| 450-474 | 4 | |
| 475-499 | 5 | |
| 500-524 | 8 | |
| 525-549 | 5 | |
| 550-574 | 3 | |
| 575-599 | | 2 |
| 600-624 | 2 | |
| 625-649 | 1 | 1 |
| 650-674 | | 2 |
| 675-699 | | |
| 700-724 | | |
| 725-749 | 1 | 1 |
| TOTAL | 83 | 39 |

Table 24. Estimated catch and mean weight (kg) of harvested fish, other than walleye, from Little McDonald Lake in 1992.

| Species | Number of fish | | Mean weight |
|---|---|---|---|
| | Harvested | Released | |
| Largemouth bass | 640 | 841 | 0.50 |
| Northern pike | 352 | 1,184 | 0.84 |
| Rock bass | 8 | 8 | 0.25 |
| Black crappie | 207 | 44 | 0.20 |
| Sunfish | 446 | 706 | 0.49 |
| Yellow perch | 4 | NE | 0.11 |

NE = not estimated

Table 25. Length distributions of Big Sand Lake walleye captured during the spawning run in 1988 (Minnesota DNR files) and from 1990-1992 (this study).

| Length (mm) | Males | | | | Females | | | |
|---|---|---|---|---|---|---|---|---|
| | 1988 | 1990 | 1991 | 1992 | 1988 | 1990 | 1991 | 1992 |
| 305-329 | 4 | 2 | 1 | 2 | | | | |
| 330-355 | 30 | 13 | 6 | 6 | | | 1 | |
| 356-380 | 117 | 80 | 44 | 16 | | | | |
| 381-405 | 147 | 160 | 89 | 63 | 1 | | 1 | |
| 406-431 | 133 | 182 | 115 | 100 | | 4 | 7 | 1 |
| 432-456 | 51 | 147 | 121 | 112 | 4 | 11 | 18 | 9 |
| 457-482 | 54 | 111 | 99 | 119 | 18 | 17 | 52 | 30 |
| 483-507 | 25 | 102 | 83 | 65 | 14 | 27 | 94 | 75 |
| 508-532 | 31 | 98 | 59 | 79 | 10 | 31 | 116 | 61 |
| 533-558 | 18 | 91 | 67 | 60 | 14 | 33 | 94 | 53 |
| 559-583 | 17 | 75 | 57 | 50 | 12 | 26 | 51 | 53 |
| 584-609 | 10 | 50 | 37 | 46 | 13 | 22 | 31 | 40 |
| 610-634 | 6 | 24 | 21 | 23 | 22 | 18 | 21 | 21 |
| 635-659 | | 8 | 9 | 10 | 21 | 45 | 29 | 18 |
| 660-685 | | 1 | 1 | 1 | 3 | 49 | 40 | 19 |
| 686-710 | | | | | 8 | 37 | 45 | 22 |
| 711-736 | | | 1 | | 11 | 22 | 20 | 20 |
| 737-761 | | | | | 7 | 13 | 9 | 6 |
| 762-786 | | | | | 2 | 8 | 0 | 3 |
| 787-812 | | | | | 2 | 2 | | 3 |
| 813-837 | | | | | | | 1 | |
| TOTAL | 643 | 1,144 | 810 | 752 | 162 | 365 | 640 | 434 |

Table 26. Age distributions of walleye captured at the inlet to Big Sand Lake during the spawning run in 1988[a].

| Age | Males | Females |
|---|---|---|
| 2 | 2 | |
| 3 | 36 | |
| 4 | 379 | 26 |
| 5 | 95 | 20 |
| 6 | 47 | 17 |
| 7 | 39 | 45 |
| 8 | 13 | 18 |
| 9 | 5 | 2 |
| 10 | 6 | |
| 11 | 16 | 12 |
| 12 | 2 | 4 |
| 13 | | 6 |
| 14 | 3 | 3 |
| 15 | | 4 |
| 16 | | 1 |
| 17 | | 2 |
| 18 | | 1 |
| TOTAL | 643 | 161 |

[a] Minnesota DNR files.

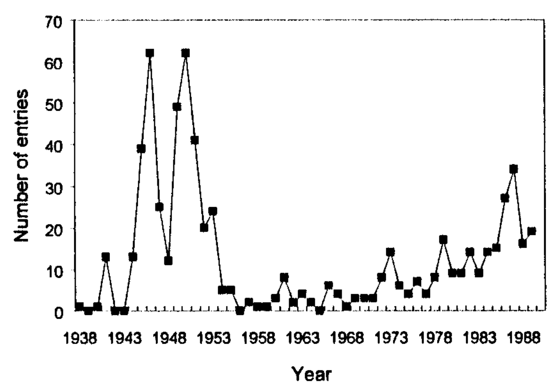


Figure 5. Number of trophy (>3.18 kg) walleye entries from Big Sand Lake, 1932-1989, in the Fuller's Golden Book Fishing Contest (Olson and Cunningham 1987).

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