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POPULATION DYNAMICS AND HARVEST OF MAINTAINED WALLEYE POPULATIONS IN TWO LAKES OF THE SOUTHERN MINNESOTA AGRICULTURAL REGION[1]

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Abstract.--Walleye *Stizostedion vitreum* fisheries in two ecologically different lakes declined steadily from 1988 to 1990, reflecting passage of a strong 1986 year class and low contributions from heavy 1988 fingerling stockings. Total annual mortality rate estimates for Madison Lake walleye age 4 and older were 48 and 46% for 1988-89 and 1989-90, respectively. For the same periods, Elysian Lake estimates were 39 and 75%, respectively. With high mortality and near zero recruitment, the Elysian Lake fishery collapsed in 1990. Annual exploitation estimates of age-4 and older walleye ranged from 25-37% for Madison Lake and from 16-50% for Elysian Lake. In terms of yield and mean size of harvested walleye, both lakes provided quality angling. Annual yields from Madison Lake averaged 8.4 kg/hectare over three fishing seasons (range 3.3 to 14.1 kg/hectare). Before the population collapse, Elysian Lake yields were 4.7 and 4.0 kg/hectare. Mean weights of harvested walleye were 0.88 kg (0.71-1.04 kg) from Madison Lake and 0.73 kg (0.69-0.82 kg) from Elysian Lake. Natural reproduction provided more than half the harvest of the 1986 year class in Madison Lake. It was not evaluated in Elysian Lake. Panfish dominated the Madison Lake harvest, while walleye comprised 2-13% of the annual harvest and 9-29% of the annual yield. In Elysian Lake, walleye comprised 48% of the harvest in 1988-89 and < 1% in 1990-91. The bullhead (primarily black bullhead *Ameiurus melas*) harvest increased nearly 6,000% during the period. A winter aeration system in Elysian Lake helped maintain a popular walleye fishery by reducing the frequency of partial winterkills, but may have contributed to the dominance of bullhead in the community.

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Introduction

Walleye *Stizostedion vitreum* are intensively managed in many lakes of the agricultural region of southern Minnesota, but results are poorly understood. Originally uncommon in the region, walleye have been widely introduced and provide angling in lakes where little or no opportunity for this species previously existed. Because of marginal walleye spawning habitat, management consists of fry and fingerling stocking.

Walleye stocking to provide viable fisheries where natural reproduction is limited or lacking has a long history in North America, and results have varied. Laarman (1978) reviewed 40 maintenance stocking cases, and reported a 33% success rate. A review of more recent case histories indicated that success rates have not changed appreciatively (Ellison and Franzin 1992). Groebner (1959, 1960) found that maintenance stocking produced walleye fisheries in two southern Minnesota centrarchid lakes with annual yields as high as 3.6 and 5.3 kg/hectare.

The success of a walleye stocking program is strongly influenced by fishing pressure and harvest (Laarman 1978). Thus, information on return to the angler of stocked walleye, and knowledge of population and harvest statistics on maintained populations is essential for biologically sound management. While considerable angler attention has been focused on southern Minnesota's maintained fisheries, knowledge of population dynamics and angler use of stocked walleye is limited. Most available walleye population and harvest statistics in Minnesota were collected from lakes in the central and northern parts of the state. Relatively high lake productivity and longer growing seasons in southern Minnesota suggest that fisheries in this region should be examined. Data gathered from southern Minnesota lakes in the 1950's (MNDNR files) indicated that southern walleye gain an early advantage, and remain about a year ahead of the statewide mean length at age (Scidmore 1970a).

Objectives of this study were to estimate for two southern Minnesota lakes (1) walleye population numbers, (2) rates of walleye total mortality, exploitation, and growth, (3) walleye age distribution and species composition of the angler harvest, and (4) fishing pressure, catch rates, harvest, and yield for all species.

Study Lakes

Madison Lake, located in Blue Earth County about 44°10'N latitude, has a surface area of 451 hectares (Quade et al. 1977). The lake is largely littoral (65% is ≤4.6 m deep), with mean and maximum depths of approximately 3.7 and 18.0 m, respectively. The 15.8 km shoreline has extensive domestic development, and the watershed is largely fertile agricultural land. A 1987 lake survey reported a total alkalinity of 140 mg/L as $CaCO_3$ (MNDNR files). The MNDNR ecological classification is Class 32 (Schupp 1992). Extensive cattail fringes exist in bays to the northeast and southwest. Macrophyte beds are common, and the lake is susceptible to mild algal blooms, but it has no history of winterkill. Walleye spawning habitat is marginal.

Fish taxa harvested from Madison Lake during the study were gar *Lepisosteus* sp. (both *L. osseus* and *L. platostomus* occur in the lake), bowfin *Amia calva*, northern pike *Esox lucius*, carp *Cyprinus carpio*, white sucker *Catostomus commersoni*, bigmouth buffalo *Ictiobus cyprinellus*, black bullhead *Ameiurus melas*, yellow bullhead *Ameiurus natalis*, white bass *Morone chrysops*, bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, white crappie *Pomoxis annularis*, black crappie *Pomoxis nigromaculatus*, yellow perch *Perca flavescens*, walleye, and freshwater drum *Aplodinotus grunniens*. Carp, bigmouth buffalo, and black bullhead support a commercial fishery. Quillback *Carpoides cyprinus*, channel catfish *Ictalurus punctatus*, green sunfish *Lepomis cyanellus*, and pumpkinseed *Lepomis gibbosus* are present. Forage species present are gizzard shad *Dorosoma cepedianum*, golden shiner *Notemigonus crysoleucas*, emerald shiner *Notropis atherinoides*, common shiner *Notropis cornutus*, spottail shiner *Notropis hudsonius*, fathead minnow *Pimephales promelas*, and johnny darter *Etheostoma nigrum*.

Elysian Lake, located in Le Sueur and Waseca Counties about 44°10'N latitude, has a surface area of 767 hectares (Quade et al. 1977). Mean and maximum depths are 2.1 and 3.7 m, respectively. The approximately 21 km of shoreline consists largely of tilled fields and pasture with some hardwood fringe. The watershed is mostly fertile farmland with sandy-clay loam soils. Rooted aquatic plants and cattail fringe are common in shoal waters. A 1988 lake survey reported a total alkalinity of 167 mg/L as $CaCO_3$ (MNDNR files). The MNDNR ecological classification is Class 41 (Schupp 1992). The lake is highly fertile, and prone to dense algal blooms and periodic winterkill. This led to the installation of a winter aeration system in 1978 (Bandow 1986).

The Elysian Lake fish community is usually heavily dominated by carp and black bullhead which, with bigmouth buffalo, support a commercial fishery. Because of winterkill conditions and poor spawning habitat, walleye, northern pike, and panfish are stocked frequently to provide recreational angling opportunities. All species listed in Madison Lake, except gar, bowfin, and emerald shiner, have been reported to occur in Elysian Lake at one time or another. However, because of frequent winterkill, a definite species assemblage cannot be described. Gizzard shad disappeared several years ago.

Methods

Spring sampling and tagging of (primarily mature) walleye were conducted four consecutive years, 1987-90. Sampling usually began immediately after ice-out. The only exception was 69 Elysian Lake walleye that were captured in a commercial seine beneath the ice on 5 March 1988. A variety of sampling gears were used, particularly in 1987 and 1988. Sex ratios of catches differed by gear (Table 1) and confounded efforts to make reliable population estimates. Gill nets used in 1987 and 1988 were standard experimental nets with five 15 m panels of multifilament nylon mesh graded from 19 to 64 mm square measure. Gill nets used in 1989 and 1990 consisted of four 15 m panels of monofilament nylon mesh graded from 38 to 76 mm square measure. Gill net sets were of approximately 30 min duration. Serially numbered disk dangler (Carlin) tags were attached to walleye through muscle tissue between the dorsal fins with single strands of No. 20 stainless steel wire. A hole was punched in the caudal fin (upper lobe on males and lower lobe on females) of each tagged fish to measure tag loss. Total lengths of all tagged walleye were recorded and a scale sample was collected from each. Weights were measured when conditions were favorable.

In most years, catches were dominated by males and few tagged females were recaptured. To avoid the bias resulting from varying sex

Table 1. Sex ratios of Madison and Elysian Lake walleye captured with various sampling gear.

Gear	*N*	Gender: Male	Female	Unsexed	Male:fem
Madison Lake					
1987					
Gill net	12	6	0	6	
Trap net	52	21	30	1	0.700
Seine	11	4	7	0	0.571
Total	75	31	37	7	0.838
1988					
Gill net	443	352	39	52	9.026
Trap net	67	37	29	1	1.276
Electro[a]	8	4	3	1	1.333
Total	518	393	71	54	5.535
1989					
Gill net	768	580	150	38	3.867
Seine	5	5	0	0	
Total	773	585	150	38	3.900
1990					
Gill net	726	601	119	6	5.050
1991					
Gill net	277	208	67	2	3.104
Elysian Lake					
1987					
Seine	306	100	177	29	0.565
1988					
Gill net	272	259	8	5	32.375
Trap net	158	27	47	84	0.574
Seine	69	19	1	49	19.000
Box trap	2	0	0	2	
Total	501	305	56	140	5.446
1989					
Gill net	364	326	33	5	9.879
Trap net	3	1	1	1	1.000
Total	367	327	34	6	9.618
1990					
Gill net	191	166	18	7	9.222

[a] Boom shocker.

ratios, population estimates were made of mature male walleye with the modified Schnabel method (Ricker 1975). Female population estimates were derived from the male estimates by applying estimates of sex ratios of the sampled populations. These were derived from catch data in two consecutive years. For instance, the 1988 spring male:female ratio in Madison Lake was calculated as the product of the male:female ratio of walleye tagged in 1988 and the male:female ratio of all walleye caught in spring 1989 divided by the male:female ratio of recaptures of 1988 tags in 1989 (Table 2). Unsexed fish were disregarded. The same procedure was used for the 1989 and 1990 spring populations in Madison Lake. Too few fish were tagged in Madison Lake in 1987 to allow a population estimate.

A lack of recaptures of females tagged the previous spring in Elysian Lake negated sex ratio estimates of the 1988, 1989, and 1990 populations. Thus, the 1987 sex ratio estimate was used to derive female population estimates in Elysian Lake for those years. The 1987 Schnabel population estimate for Elysian Lake was made from combined sexes captured by commercial seine.

Ninety-seven percent of the tagged walleye in each lake were aged from scales, and ages were assigned to the remainder, independently by sex, with an age-length key (Ketchen 1949). Male and female population estimates were categorized independently by age and then combined. Estimates of annual survival rates (S) of age-4 and older walleye were calculated by dividing spring population estimates of age-5 and older fish by population estimates of age-4 and older fish the previous spring. Estimates of annual rates of accession (r) of walleye age 4 and older were calculated from the equation $N_2/(SN_1)$ (Ricker 1975).

Roving creel surveys were conducted on Madison and Elysian lakes during the four fishing seasons from mid-May 1987 through mid-February 1991. Actions of an unreliable survey clerk compelled us to reject the summer 1987 data. Except for the opening weekend of the fishing season each year, when four clerks were employed, one clerk sampled one lake each 8 h workday. Workdays were partitioned into early or late shifts. The survey was stratified by month, and by weekday or weekend-holiday. Four activity counts were made each workday at approximately 2 h intervals. Between counts,

Table 2. Sex ratio estimates of spring sampled walleye populations in Madison and Elysian lakes.

	Number of fish			Male:female
	Males	Females	Male:female	estimate
	Madison	**Lake**		
Walleye tagged in 1988	373	70	5.329	
Total walleye catch in 1989	585	150	3.900	
Captures of 1988 tags in 1989	60	2	30.000	
Sampled walleye population in 1988				0.693
Fish tagged in 1989	521	145	3.593	
Total catch in 1990	601	119	5.050	
Captures of 1989 tags in 1990	88	4	22.000	
Sampled walleye population in 1989				0.825
Fish tagged in 1990	544	115	4.730	
Total catch in 1991	208	67	3.104	
Captures of 1990 tags in 1991	60	8	7.500	
Sampled walleye population in 1990				1.958
	Elysian	**Lake**		
Walleye tagged in 1987	100	177	0.565	
Total walleye catch in 1988	305	56	5.446	
Captures of 1987 tags in 1988	4	2	2.000	
Sampled walleye population in 1987				1.539

the clerk interviewed fishing parties and recorded their starting time, time of the interview, number in the party, numbers of fish caught by species, and demographic information. As time permitted, total lengths and weights of harvested fish were obtained. Frequently, incomplete trip interviews were updated to complete trip interviews. Night fishing by winter anglers in shelters presented a special problem because these anglers often fished beyond the 2200 h quitting time of the clerk. In such cases, the clerk recorded the time anglers estimated they would stop fishing.

Lengths of all harvested walleye were recorded, and a scale sample and the second dorsal spine were collected from most. Scales and dorsal spines were examined independently to reduce reader bias, and ages assigned by the two methods were compared. Weights were derived from weight-length models generated from samples of weighed fish. Age analysis was conducted on 34 and 36% of creel sampled walleye of unknown age from Madison and Elysian lakes, respectively. Madison Lake contained known-age walleye as all fingerlings stocked in fall 1986 were marked by removal of the left pelvic fin. Age distributions of all sampled walleye were generated with an age-length key (Ketchen 1949).

Weight-length models of creeled and spring sampled walleye were derived by least-squares regression of log transformed variables.

Results

Aging Techniques

Agreement between ages assigned from scale and dorsal spine examination of angler harvested walleye was 69% overall and generally higher among younger fish (Table 3). Agreement within ±1 year was 97%. Among age-4 and older fish (scale aged), instances in which the spine age exceeded the scale age occurred more frequently than the opposite case. Dorsal spines are reportedly more reliable indicators of age, particularly among older walleye (Campbell and Babaluk 1979; Olson 1980; Erickson 1983). Since tagged walleye were aged from scales only, the population estimates of age-4 and older walleye may have been biased downward if a disproportionate number of tagged age-4 and older fish were under-aged.

Tag Loss

Tag loss by walleye was evaluated each spring. Known tag losses by the end of the

Table 3. Agreement between walleye age assignments from scale and dorsal spine examination.

Scale Age	*N*	Percent agreement	Percent agreement within ±1 year	Percent of fish for which spine age exceeded scale age by 1 year	Percent of fish for which scale age exceeded spine age by 1 year
1	2	100	100	0	0
2	131	83	99	0	16
3	163	80	100	6	14
4	111	66	96	25	5
5	88	58	94	32	5
6	60	48	92	32	12
7	52	58	92	27	8
8	30	57	97	20	20
9	10	70	100	20	10
10	3	33	100	67	0
11	1	100	100	0	0
Total	651	69	97	17	11

study were 3-4% (Table 4). No loss of a tag was noted during the same spring that it was attached. Male spring population assessments were derived from recaptures of walleye tagged the same spring, so tag loss does not jeopardize study results. Observed cases of missing tags were easily confirmed by distinct scars at tag locations and where caudal fins had been punched.

Population Statistics

Spring populations of mature walleye in both Madison and Elysian lakes declined steadily during the study (Table 5). The population estimate in Madison Lake declined 39% between 1988 and 1989 and 21% between 1989 and 1990. The total decline over the two periods was 51%. During the same periods in Elysian Lake, estimates declined 27 and 75%, respectively, and the total decline was 82%.

Rates of mortality and accession of mature walleye were estimated only for walleye age 4 and older as it was assumed that age 4 was the first group fully recruited to the spawning population. At age 4, mean length of males in spring (all years) was 458 mm (SD=21.9 mm) in Madison Lake and 441 mm (SD=30.5 mm) in Elysian Lake. Mean length of females was 500 mm (SD=33.8 mm) in Madison Lake and 463 mm (SD=28.0 mm) in Elysian Lake.

Estimates of total annual mortality in Madison Lake were 48 and 46% in 1988-89 and 1989-90, respectively (Table 6). In Elysian Lake during the same periods, estimates were 39 and 75%, respectively. For comparison, the mean annual mortality rate of age 4-6 walleye in Madison Lake, estimated from a catch curve of the 1988-90 mean CPUE of summer walleye anglers (Ricker 1975), was 0.507 (r^2=0.999; N=3; P=0.015). Similarly, the mean annual mortality rate of age 5-8 walleye in Elysian Lake was 0.481 (r^2=0.983; N=4; P=0.009). Fishing accounted for much of the mortality in both lakes, and in 1989-90, the exploitation estimate for Elysian Lake was extraordinarily high.

Table 4. Summary of known tag losses of walleye recaptured a minimum of one year after they were tagged.

Year	Number newly tagged	Number of recaptures of fish tagged in previous years	Number of tag losses	Percent tag loss
		Madison Lake		
1987	68			
1988	491	6	0	0.0
1989	639	71	1	1.4
1990	557	124	4	3.2
1991		100	3	3.0
Total	1,755	301	8	2.7
		Elysian Lake		
1987	302			
1988	479	6	0	0.0
1989	321	24	0	0.0
1990		25	1	4.0
Total	1,102	55	1	1.8

Table 5. Spring population estimates of Madison and Elysian Lake mature walleye. Male estimates were made by the modified Schnabel method. Female estimates were derived from the male estimates and estimated population sex ratios.

				95% confidence interval	
Year	Gender	Number of recaptures	$\hat{N}$	Lower limit	Upper limit
		Madison Lake			
1987		1			
1988	Male	18	3,431	2,218	5,572
	Female	0	4,954		
	Total	18	8,385		
1989	Male	59	2,326	1,810	2,986
	Female	5	2,820		
	Total	64	5,146		
1990	Male	55	2,701	2,084	3,497
	Female	4	1,379		
	Total	59	4,080		
1991	Male	8	1,936	1,037	3,961
		Elysian Lake			
1987	Total	4	5,914[a]	2,640	14,786
1988	Male	10	2,972	1,685	5,735
	Female	0	1,932		
	Total	10	4,904		
1989	Male	19	2,158	1,411	3,453
	Female	0	1,403		
	Total	19	3,561		
1990	Male	19	538	352	861

[a]Estimate made on combined sexes sampled with a commercial seine.

Table 6. Apportionment of population estimates to age groups, and estimates of total annual mortality, exploitation, and accession of age-4 and older walleye in Madison and Elysian lakes.

Spring population estimates		Mortality of walleye ≥age 4				
≥ age 4	≥age 5	Total annual mortality (A)	Summer exploitation	Winter exploitation	Total annual exploitation (u)	Annual rate of accession (r)
			Madison Lake 1988-89			
7,201	3,956	0.477	0.347	0.020	0.366	1.187
			Madison Lake 1989-90			
4,466	3,763	0.455	0.310	0.004	0.314	1.653
			Madison Lake 1990-91			
4,021	2,432		0.235	0.012	0.246	
			Elysian Lake 1988-89			
4,683	3,142	0.392	0.266	0.115	0.382	1.069
			Elysian Lake 1989-90			
3,046	2,849	0.754	0.377	0.124	0.501	1.084
			Elysian Lake 1990-91			
811	748		0.163	0.000	0.163	

Recruitment to age 4 in Madison Lake was low in 1989, when the accession rate estimate was 1.19. An accession rate of 1.0 represents zero recruitment, while a rate of 1.92 was necessary to offset the 48% mortality between 1988 and 1989. In 1990, recruitment was better (r=1.65), and numbers of age-4 and older walleye were more stable as a result of entry of the 1986 year class which was dominant in the angler harvest during the study. In Elysian Lake, recruitment was poor in both 1989 and 1990 (r=1.07 and 1.08, respectively), and with an estimated 75% mortality of age-4 and older walleye from 1989 to 1990, the population essentially collapsed. The 1986 year class, which also was dominant in the Elysian Lake fishery, had nearly disappeared by 1990.

On average, Madison Lake walleye were longer at age than Elysian Lake walleye (Table 7). In two sample *t*-tests, mean lengths of Madison Lake males were significantly greater at all age classes ($P<0.001$). In only one case (age 4), was the difference in female mean lengths significant at the 5% level. On average, females were significantly longer than males at all ages ($P<0.001$). With one exception, differences between the sexes were larger in Elysian Lake than in Madison Lake.

Walleye in both lakes exhibited isometric growth with weight-length regression slopes very near 3 (Table 8). Slopes did not differ significantly between sexes within lakes nor among sexes between lakes ($P=0.165$-0.947). Madison Lake walleye were significantly heavier at length, on average, than Elysian Lake walleye (ANCOVA; $P<0.001$ for each sex). The adjusted mean weights of Madison Lake males and females exceeded those of Elysian Lake by 5.4 and 7.1%, respectively. Female adjusted means were 14.4 and 13.4% larger than male adjusted means in Madison and Elysian lakes, respectively. In comparisons involving Madison Lake male walleye, residual variances differed significantly ($P<0.001$).

Madison Lake Harvest

Total angling pressure on Madison Lake did not change much during the study, but seasonal angler distribution and catch composition did. Summer angling pressure estimates steadily declined 22% between 1988 and 1990 dropping from 242 to 189 h/hectare (Table 9). However, increased winter pressure compensated for this decline with yearly angling remaining at about 300 h/hectare. Northern pike provided some

Table 7. Empirical lengths (mm) at age of spring captured walleye in Madison and Elysian lakes.

Age	Males					Females				
	N	Minimum	Maximum	Mean	SD	*N*	Minimum	Maximum	Mean	SD
					Madison Lake, 1987-91					
2	25	325	402	367	18.11	1	360	360		
3	148	352	508	422	27.82	31	408	495	447	20.92
4	408	405	545	458	21.86	84	432	641	500	33.82
5	314	409	627	486	26.26	105	420	639	530	33.42
6	299	411	604	507	27.41	48	437	613	555	34.55
7	187	443	600	531	29.39	46	527	705	590	38.15
8	104	453	623	550	33.49	24	564	736	635	36.83
9	42	506	673	569	35.60	12	564	721	649	54.36
10	10	518	630	583	31.12	16	620	726	681	31.96
11						4	668	701	691	15.31
					Elysian Lake, 1987-90					
2	18	305	388	343	20.85	1	389	389		
3	106	326	462	380	34.40	39	398	490	438	21.40
4	182	337	543	441	30.49	93	410	560	463	28.02
5	217	370	585	470	23.24	41	437	620	517	36.83
6	163	425	574	491	23.13	43	446	613	550	36.40
7	94	435	565	501	27.40	29	535	674	582	31.05
8	26	444	552	515	27.59	16	556	715	620	40.30
9	9	495	555	532	17.13	10	591	653	618	20.96
10	1	572	572			1	616	616		

winter recreation for dark house spearers during earlier seasons when pressure estimates ranged from 4.5 to 8.9 h/hectare, but spearing pressure declined sharply in 1990-91.

Harvest rates of walleye and northern pike declined steadily during the period 1988-1991. Summer rates (all anglers considered) declined from 0.07 walleye and 0.04 pike/h in 1988 to 0.02 walleye and <0.01 pike/h in 1990 (Table 10). Angler harvest rates of all species combined increased during the study, but peaked during the 1989-90 fishing season. A sharp rise in crappie harvest rates largely accounted for the increase.

Winter rates of 0.02 and 0.05 walleye/h in 1987-88 and 1988-89, respectively, declined to <0.01 during the later two winters. Northern pike provided practically no winter recreation for anglers, while spearing rates of 0.10 to 0.15 pike/h during the first three winters dropped to zero in 1990-91.

Summer harvest rates for anglers that were seeking walleye only, declined from 0.12 to 0.03 fish/h from 1988 to 1990 (Table 11). Walleye-only anglers comprised 32-40% of summer anglers interviewed. In winter 1988-89, 31% of the anglers interviewed were fishing walleye, but during other winters few walleye anglers were on the ice. Harvest rates of winter walleye anglers were about 0.1 fish/h in the two seasons from 1987 through 1989, but they dropped sharply after that.

Table 8. Summaries of least-squares regressions of $\log_{10}$ weight on $\log_{10}$ total length. Samples were composites of walleye spring catches from 1988 through 1990.

		Regression statistics			
	N	Intercept	Slope	r^2	$s_{Y\|X}$
		Madison Lake			
Males	1,274	-5.069	3.023	0.917	0.039
Females	293	-4.908	2.985	0.915	0.049
		Elysian Lake			
Males	669	-4.939	2.965	0.919	0.046
Females	78	-4.960	2.993	0.909	0.047

Species composition of the Madison Lake harvest estimates changed during the study with a large increase in crappie numbers, and a decrease in walleye and northern pike numbers (Table 12). Thus, numbers of fish harvested fluctuated widely while yield remained relatively stable (Table 13). Crappie dominated the harvest in all years accounting for 52 to 76% of the total estimate during the three angling seasons. The crappie harvest peaked in 1988-89 at

Table 9. Estimates of angling and spearing pressure on Madison and Elysian lakes.

Year	Total hours	SE	Hours per hectare	SE	Year	Total hours	SE	Hours per hectare	SE
	Madison Lake					**Elysian Lake**			
	Summer angling					**Summer angling**			
1988	108,963	12,134	241.8	26.9	1988	43,544	8,155	56.8	10.6
1989	97,560	9,179	216.5	20.4	1989	38,465	5,334	50.1	7.0
1990	85,310	14,197	189.3	31.5	1990	31,243	3,639	40.7	4.7
	Winter angling					**Winter angling**			
1987-88	13,030	890	28.9	2.0	1987-88	14,907	1,418	19.4	1.8
1988-89	24,970	1,934	55.4	4.3	1988-89	28,068	1,422	36.6	1.9
1989-90	45,463	1,901	100.9	4.2	1989-90	22,331	1,259	29.1	1.6
1990-91	45,570	1,893	101.1	4.2	1990-91	143	41	0.2	0.1
	Total angling					**Total angling**			
1988-89	133,933	12,287	297.2	27.2	1988-89	71,612	8,278	93.4	10.8
1989-90	143,023	9,374	317.4	20.8	1989-90	60,796	5,481	79.3	7.2
1990-91	130,880	14,323	290.5	31.8	1990-91	31,386	3,639	40.9	4.7
	Winter spearing					**Winter spearing**			
1987-88	3,397	382	7.5	0.8	1987-88	4,767	706	6.2	0.9
1988-89	4,000	787	8.9	1.7	1988-89	113	130	0.1	0.2
1989-90	2,008	264	4.5	0.6	1989-90	197	73	0.3	0.1
1990-91	199	76	0.4	0.2	1990-91	0	0	0.0	0.0

Table 10. Madison Lake harvest rate estimates.

Species	1987-88		1988-89		1989-90		1990-91	
	Number per hour	SE	Number per hour	SE	Number per hour	SE	Number per hour	SE
			Summer angling					
Northern pike			0.042	0.005	0.010	0.001	0.004	0.001
Bullhead[a]			0.005	0.001	0.005	0.001	0.005	0.001
White bass			0.004	0.001	0.004	0.001	0.002	0.001
Bluegill			0.126	0.017	0.138	0.017	0.145	0.022
Largemouth bass			0.011	0.002	0.007	0.002	0.012	0.005
Crappie[b]			0.230	0.019	0.514	0.038	0.358	0.022
Yellow perch			0.001	<0.001	0.001	<0.001	0.001	<0.001
Walleye			0.070	0.013	0.039	0.004	0.015	0.003
Freshwater drum			0.001	0.001	0.006	0.001	0.006	0.002
All species			0.490	0.033	0.725	0.044	0.546	0.026
			Winter angling					
Northern pike	0.000	0.000	0.000	0.000	0.000	0.000	0.001	<0.001
White bass	0.001	0.001	0.036	0.017	0.004	0.003	0.003	0.001
Bluegill	0.245	0.054	0.053	0.021	0.238	0.040	0.123	0.019
Largemouth bass	0.001	0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001
Crappie	0.481	0.067	0.385	0.037	1.120	0.063	0.472	0.033
Yellow perch	0.269	0.058	0.006	0.003	0.011	0.006	0.008	0.003
Walleye	0.019	0.005	0.045	0.007	0.002	0.001	0.002	0.001
All species	1.015	0.105	0.526	0.044	1.376	0.084	0.609	0.036
			Winter spearing					
Gar	0.000	0.000	0.002	0.001	0.004	0.004	0.000	0.000
Bowfin	0.000	0.000	0.007	0.003	0.003	0.003	0.112	0.116
Northern pike	0.095	0.020	0.151	0.021	0.097	0.021	0.000	0.000
Carp	0.000	0.000	0.010	0.006	0.000	0.000	0.000	0.000
White sucker	0.000	0.000	0.007	0.006	0.000	0.000	0.000	0.000
Bigmouth buffalo	0.000	0.000	0.000	0.000	0.004	0.004	0.000	0.000
Bullhead	0.000	0.000	0.017	0.015	0.000	0.000	0.112	0.116
All species	1.015	0.105	0.183	0.030	0.108	0.022	0.223	0.233

[a]Primarily black bullhead. [b]Black crappie and white crappie.

Table 11. Walleye harvest rate estimates for all anglers and for anglers that indicated they were seeking walleye only.

	All anglers			Walleye anglers			
Years	Number interviewed	Harvest rate (no./h)	SE	Number interviewed	Percent of all anglers	Harvest rate (no./h)	SE
			Madison Lake				
			Summer				
1988	2,998	0.070	0.013	985	32.9	0.120	0.012
1989	2,721	0.039	0.004	1,093	40.2	0.083	0.008
1990	2,810	0.015	0.003	888	31.6	0.033	0.004
			Winter				
1987-88	546	0.019	0.005	15	2.7	0.098	0.103
1988-89	763	0.045	0.007	238	31.2	0.100	0.021
1989-90	1,123	0.002	0.001	80	7.1	0.010	0.007
1990-91	1,196	0.002	0.001	108	9.0	0.017	0.009
			Elysian Lake				
			Summer				
1988	1,579	0.072	0.014	1,008	63.8	0.086	0.010
1989	1,537	0.071	0.008	1,113	72.4	0.086	0.009
1990	1,390	0.009	0.002	407	29.3	0.031	0.005
			Winter				
1987-88	680	0.090	0.011	384	56.5	0.089	0.013
1988-89	793	0.077	0.009	764	96.3	0.060	0.007
1989-90	731	0.049	0.007	680	93.0	0.049	0.007
1990-91	11	0.000	0.000	10	90.9	0.000	0.000

>100,000 fish. Crappie accounted for 25% of the total annual yield in 1988-89, and more than 60% in each of the 1989-90 and 1990-91 seasons.

The walleye harvest declined steadily from an estimated 8,800 in 1988-89 to 1,400 in 1990-91. Walleye comprised 13% of the annual harvest and 29% of the annual yield in 1988-89, and 1.9% of the harvest and 8.6% of the yield in 1990-91. Northern pike comprised 6.8% and 25% of the angler harvest and yield in 1988-89, respectively. In 1990-91, it comprised 0.5% and 3.4%, respectively. Bluegill was a steady contributor comprising 18-24% of the annual harvest and 10-13% of the annual yield.

Crappie dominance was greatest in winter when the species comprised 73 to 81% of harvested fish. Walleye comprised 8.5% of the winter harvest in 1988-89 but <0.5% thereafter. Together crappie and bluegill accounted for 83% of the winter harvest in 1988-89 and more than 97% thereafter. Most walleye were caught during the summer seasons when 87-98% of the total annual walleye harvest occurred. Nearly all of the pike were harvested during summer.

The size of harvested walleye from Madison Lake steadily increased during the three fishing seasons 1988-91. This was a result of the relatively strong 1986 year class moving through the system. Mean total lengths ranged from 409 mm during the 1988-89 season to 459 mm during the 1990-91 season (Table 14). Mean weights ranged from 714 to 1,040 g.

The 1986 year class was dominant in the Madison Lake walleye harvest throughout the study (Table 15). At ages 2, 3, and 4, it comprised 58, 59, and 34% of the total walleye harvest, respectively. A fingerling stocking contributed a portion of those 1986 walleye, but natural reproduction contributed the majority in two of the three fishing seasons. Nearly 21,000 (hand count) fingerlings, or 46.4/hectare, were released in Madison Lake in fall 1986 (Table 16). These marked fish comprised 35, 54, and 30% of the harvest of the 1986 year class at ages 2, 3, and 4, respectively (Table 17). They comprised 20, 32, and 10% of the total walleye harvest, respectively. In 1988, the stocked fish may not have been as fully recruited as the naturally produced walleye of the same year

Table 12. Madison Lake harvest estimates.

Species	1987-88 Number	1987-88 SE	1987-88 Number per hectare	1988-89 Number	1988-89 SE	1988-89 Number per hectare	1989-90 Number	1989-90 SE	1989-90 Number per hectare	1990-91 Number	1990-91 SE	1990-91 Number per hectare
Summer angling												
Northern pike				4,539	865	10.1	963	183	2.1	310	92	0.7
Bullhead[a]				536	164	1.2	493	134	1.1	446	148	1.0
White bass				435	119	1.0	393	112	0.9	206	68	0.5
Bluegill				13,729	1,820	30.5	13,510	1,773	30.0	12,337	1,936	27.4
Largemouth bass				1,167	201	2.6	727	217	1.6	982	473	2.2
Crappie[b]				25,061	3,592	55.6	50,171	4,629	111.3	30,507	4,225	67.7
Yellow perch				77	44	0.2	90	47	0.2	77	37	0.2
Walleye				7,661	1,803	17.0	3,806	654	8.4	1,273	373	2.8
Freshwater drum				149	65	0.3	558	170	1.2	482	217	1.1
All species				53,354	6,649	118.4	70,711	6,151	156.9	46,620	5,964	103.5
Winter angling												
Northern pike	0	0	0.0	0	0	0.0	0	0	0.0	28	20	0.1
White bass	10	11	<0.1	900	427	2.0	199	119	0.4	140	52	0.3
Bluegill	3,193	736	7.1	1,330	537	3.0	10,832	1,874	24.0	5,611	904	12.5
Largemouth bass	16	17	<0.1	18	18	<0.1	12	12	<0.1	23	23	0.1
Crappie	6,269	984	13.9	9,610	1,187	21.3	50,930	3,610	113.0	21,515	1,764	47.7
Yellow perch	3,499	789	7.8	158	78	0.4	479	278	1.1	342	123	0.8
Walleye	243	71	0.5	1,118	207	2.5	87	45	0.2	106	41	0.2
All species	13,230	1,648	29.4	13,134	1,516	29.1	62,539	4,672	138.8	27,765	2,013	61.6
Total angling												
Northern pike				4,539	865	10.1	963	183	2.1	338	94	0.8
Bullhead				536	164	1.2	493	134	1.1	446	148	1.0
White bass				1,335	443	3.0	592	163	1.3	346	86	0.8
Bluegill				15,059	1,898	33.4	24,342	2,580	54.0	17,948	2,137	39.8
Largemouth bass				1,185	202	2.6	739	217	1.6	1,005	474	2.2
Crappie				34,671	3,783	76.9	101,101	5,870	224.4	52,022	4,578	115.5
Yellow perch				235	90	0.5	569	282	1.3	419	128	0.9
Walleye				8,779	1,815	19.5	3,893	656	8.6	1,379	375	3.1
Freshwater drum				149	65	0.3	558	170	1.2	482	217	1.1
All species				66,488	6,820	147.6	133,250	7,724	295.7	74,385	6,295	165.1
Winter spearing												
Gar	0	0	0.0	6	6	<0.1	8	8	<0.1	0	0	0.0
Bowfin	0	0	0.0	28	15	0.1	6	6	<0.1	22	25	<0.1
Northern pike	323	80	0.7	603	139	1.3	194	48	0.4	0	0	0.0
Carp	34	21	0.1	0	0	0.0	0	0	0.0	0	0	0.0
White sucker	0	0	0.0	27	27	0.1	0	0	0.0	0	0	0.0
Bigmouth buffalo	0	0	0.0	0	0	0.0	8	9	<0.1	0	0	0.0
Bullhead	0	0	0.0	68	62	0.2	0	0	0.0	22	25	<0.1
All species	357	83	0.8	732	186	1.6	216	52	0.5	44	49	0.1

[a]Primarily black bullhead.
[b]Black crappie and white crappie.

Table 13. Madison Lake yield estimates.

	1987-88			1988-89			1989-90			1990-91		
Species	Kg	SE	Kg per hectare	Kg	SE	Kg per hectare	Kg	SE	Kg per hectare	Kg	SE	Kg per hectare
Summer angling												
Northern pike				5,483	1,680	12.2	1,378	428	3.1	539	231	1.2
Bullhead[a]				239	32	0.5	170	24	0.4	180	NA[b]	0.4
White bass				326	97	0.7	290	99	0.6	146	54	0.3
Bluegill				1,994	400	4.4	2,030	347	4.5	1,574	309	3.5
Largemouth bass				938	283	2.1	728	NA	1.6	829	458	1.8
Crappie[c]				3,835	663	8.5	7,552	785	16.8	6,646	480	14.7
Yellow perch				9	NA	<0.1	10	6	<0.1	9	NA	<0.1
Walleye				5,511	2,753	12.2	3,359	1,613	7.5	1,373	692	3.0
Freshwater drum				61	35	0.1	156	66	0.3	140	NA	0.3
All species				18,395	NA	40.8	15,673	NA	34.8	11,437	NA	25.4
Winter angling												
Northern pike	0	0	0.0	0	0	0.0	0	0	0.0	49	38	0.1
White bass	11	NA	<0.1	619	346	1.4	150	94	0.3	99	42	0.2
Bluegill	463	178	1.0	177	83	0.4	1,215	359	2.7	704	170	1.6
Largemouth bass	18	19	<0.1	9	9	<0.1	12	NA	<0.1	19	20	<0.1
Crappie	1,031	303	2.3	1,532	367	3.4	9,062	836	20.1	4,874	637	10.8
Yellow perch	401	166	0.9	18	NA	<0.1	55	46	0.1	39	NA	0.1
Walleye	239	191	0.5	841	355	1.9	101	105	0.2	114	69	0.3
All species	2,163	NA	4.8	3,194	NA	7.1	10,595	NA	23.5	5,898	NA	13.1
Total angling												
Northern pike				5,483	1,680	12.2	1,378	428	3.1	588	234	1.3
Bullhead				239	32	0.5	170	24	0.4	180	NA	0.4
White bass				944	359	2.1	440	136	1.0	245	69	0.5
Bluegill				2,170	408	4.8	3,245	499	7.2	2,277	352	5.1
Largemouth bass				947	283	2.1	740	NA	1.6	849	458	1.9
Crappie				5,367	758	11.9	16,614	1,147	36.9	11,520	798	25.6
Yellow perch				27	NA	0.1	65	46	0.1	48	NA	0.1
Walleye				6,352	2,776	14.1	3,460	1,616	7.7	1,488	695	3.3
Freshwater drum				61	35	0.1	156	66	0.3	140	NA	0.3
All species				21,590	NA	47.9	26,268	NA	58.3	17,335	NA	38.5
Winter spearing												
Gar	0	0	0.0	2	2	<0.1	9	9	<0.1	0	0	0.0
Bowfin	0	0	0.0	56	35	0.1	16	16	<0.1	0	0	0.0
Northern pike	488	243	1.1	1,078	403	2.4	357	145	0.8	0	0	0.0
Carp	NA	NA	NA	0	0	0.0	0	0	0.0	0	0	0.0
White sucker	0	0	0.0	18	18	<0.1	0	0	0.0	0	0	0.0
Bigmouth buffalo	0	0	0.0	0	0	0.0	42	NA	0.1	0	0	0.0
Bullhead	0	0	0.0	38	36	0.1	0	0	0.0	NA	NA	NA

[a] Primarily black bullhead.
[b] Not available.
[c] Black crappie and white crappie.

Table 14. Length and weight summaries of walleye harvested from Madison and Elysian lakes.

Years	*N*	Total length (mm)				Weight (g)			
		Minimum	Maximum	Mean	SD	Minimum	Maximum	Mean	SD
Madison Lake									
Summer									
1988	490	236	703	407	87.0	108	3,456	709	530.7
1989	349	302	738	436	86.1	233	4,218	883	644.1
1990	116	281	690	461	103.5	188	3,257	1,058	68.5
Winter									
1987-88	15	255	750	430	127.6	134	4,244	958	1,081.0
1988-89	87	259	654	421	68.3	145	2,747	742	448.6
1989-90	5	281	711	435	173.1	188	3,582	1,121	1,412.4
1990-91	9	299	518	435	63.2	229	1,310	799	314.6
Summer and winter combined									
1988-89	577	236	703	409	84.5	108	3,456	714	519.1
1989-90	354	281	738	436	88.0	188	4,218	872	661.2
1990-91	125	281	690	459	101.1	188	3,257	1,040	107.2
Elysian Lake									
Summer									
1988	176	243	685	394	87.9	129	3,113	660	457.4
1989	320	291	644	422	77.7	224	2,575	784	480.8
1990	54	325	650	406	71.4	314	2,649	687	460.1
Winter									
1987-88	66	165	545	412	84.2	39	1,541	732	385.9
1988-89	200	249	652	406	87.3	139	2,675	721	532.9
1989-90	135	318	638	445	77.4	294	2,502	909	509.0
1990-91	0								
Summer and winter combined									
1988-89	376	243	685	400	87.6	129	3,113	693	499.0
1989-90	455	291	644	429	77.7	224	2,575	821	489.4
1990-91	54	325	650	406	71.4	314	2,649	687	460.1

Table 15. Age distributions of walleye harvested from Madison and Elysian lakes.

Age	Madison Lake			Elysian Lake		
	Summer harvest	Winter harvest	Total harvest	Summer harvest	Winter harvest	Total harvest
			1988-89			
1	0	51	51	36	248	284
2	4,275	784	5,059	1,337	1,067	2,404
3	811	141	952	517	302	819
4	1,357	51	1,408	588	259	847
5	421	51	472	571	75	646
6	296	39	335	18	65	83
≥7	499	0	499	72	140	212
Total	7,659	1,117	8,776	3,139	2,156	5,295
			1989-90			
1	0	35	35	0	16	16
2	109	17	126	178	580	758
3	2,268	17	2,285	1,393	113	1,506
4	404	0	404	170	73	243
5	502	0	502	416	153	569
6	142	0	142	289	89	378
≥7	382	17	399	271	64	335
Total	3,807	86	3,893	2,717	1,088	3,805
			1990-91			
1	0	12	12	0	0	0
2	274	47	321	6	0	6
3	66	0	66	160	0	160
4	428	47	475	77	0	77
5	165	0	165	6	0	6
6	99	0	99	33	0	33
≥7	241	0	241	17	0	17
Total	1,273	106	1,379	299	0	299

Table 16. Walleye stocking records[a] for Madison and Elysian lakes, 1978-1989.

	Madison Lake				Elysian Lake			
Year	Size group[b]	Number per kg	Number stocked	Kg stocked	Size group[b]	Number per kg	Number stocked	kg stocked
1978	Fingerling	37.2	16,336	439	Fry		1,000,000	
					Fingerling	87.6	9,810	112
1979	Fingerling	34.4	21,412	622	Fry		1,000,000	
					Adult	1.7	5	3
1980	Fry		1,000,000		Fry		1,000,000	
	Fingerling	6.6	1,506	228	Fingerling	27.5	20,399	743
	Yearling	13.2	5,982	453	Yearling	11.0	1,973	180
1981	Yearling	11.0	6,800	617	Yearling	6.6	2,037	307
					Adult	10.1	8,661	854
1982	Fingerling	26.5	16,468	622	Fingerling	30.4	9,016	297
	Yearling	8.3	5,972	718	Yearling	16.4	6,344	386
1983	Fingerling	13.4	5,616	419	Fry		1,600,000	
	Yearling	9.9	1,016	103				
	Adult	4.4	512	116				
1984	Fingerling	44.1	15,700	356	Adult	2.8	31	11
	Yearling	4.4	110	25				
	Adult	4.4	1,800	408				
1985	Yearling	1.9	1,556	840	Fingerling	18.4	7,935	431
					Yearling	9.2	4,864	529
					Adult	5.5	325	59
1986	Fingerling	37.0	20,896	565	Fingerling	87.2	93,727	1,075
1987					Fingerling	7.4	1,570	211
					Yearling	2.2	1,106	502
1988	Fingerling	52.0	26,725	514	Fingerling	108.9	60,532	556
1989	Fingerling	88.2	43,480	493	Fingerling	82.3	70,840	861

[a]MNDNR files.
[b]All fingerling stocking was done in the fall.

Table 17. Walleye harvest estimates for Madison Lake and contributions of the 1986 stocked fingerlings.

Season	Total harvest: Number	Total harvest: Percent 1986 stocked	Harvest of 1986 year class: Number	Harvest of 1986 year class: Percent stocked
		1988-89		
Summer	7,661	18.5	4,275	33.2
Winter	1,118	31.0	784	44.3
Total	8,779	20.4	5,059	35.2
		1989-90		
Summer	3,806	32.4	2,268	54.3
Winter	87	0.0	17	0.0
Total	3,893	31.9	2,285	54.1
		1990-91		
Summer	1,273	11.2	428	33.3
Winter	106	0.0	47	0.0
Total	1,379	10.4	475	30.2

class. Six different nursery lakes contributed to the 1986 stocking, and fingerling sizes varied widely from lake to lake (Table 18). Only 321 age-2 walleye were harvested in 1990-91 indicating poor results from the large 1988 fingerling stocking.

Elysian Lake Harvest

Elysian Lake angling pressure estimates, and estimates of harvest and harvest rates of walleye and northern pike declined steadily during the study. By winter 1990-91, fishing pressure on Elysian Lake was nearly absent (Table 9). Only 11 anglers (all unsuccessful) were interviewed through 24 January when the creel survey was suspended because low dissolved oxygen concentrations prompted authorities to open the lake to liberalized fishing methods. The aeration system was not operated in winter 1990-91 to encourage winterkill of undesirable species. Summer angling on Elysian Lake declined more modestly because increasing numbers of bullhead anglers partially compensated for the decline in walleye and pike anglers. In 1990, only 29% of summer anglers interviewed indicated that they were seeking walleye compared with 64 and 72% in 1988 and 1989, respectively (Table 11). Summer bullhead anglers increased from 5 and 7% in 1988 and 1989, respectively, to 49% in 1990.

Summer harvest rates of about 0.07 walleye/h were similar in 1988 and 1989, and dropped sharply to <0.01 in 1990 (Table 19). Winter harvest rates declined steadily from 0.09 in 1987-88 to zero in 1990-91. Summer and winter harvest rates of northern pike abruptly declined also, but a year sooner. Bullhead (primarily black bullhead) harvest rates increased by a factor of 85 from 0.063/h in summer 1988 to more than 5/h in summer 1990. Disparities between catch rates calculated with all anglers and with walleye-only anglers in the denominator were small during other periods compared with summer 1990 (Table 11). This is not surprising because most anglers were specifically seeking walleye during those other periods, and many more were fishing for walleye northern pike.

Table 18. Numbers, length summaries, and marking mortality summaries of marked (left pelvic fin removed) walleye fingerlings stocked in Madison Lake from various nursery lakes in fall 1986. The Eagle Lake fish were confined in a crib submerged in a pond for the mortality assessment. All other assessments were conducted in fiberglass, indoor raceways.

Nursery lake	Number stocked	Total length (mm): N	Total length (mm): Minimum	Total length (mm): Maximum	Total length (mm): Mean	Total length (mm): SD	Marking mortality assessments: Days	Marked fish (50): Percent mortality	Marked fish (50): Percent moribundity	Unmarked fish (50): Percent mortality	Unmarked fish (50): Percent moribundity
Dog	2,162	50	134	207	154	17.5	9	0	0	0	0
Eagle[a]	1,497	50	180	246	211	14.9	7	30	18	16	12
Echo	2,487	101	110	272	190	38.3	9	0	0	0	0
Fink	10,286	53	107	142	119	6.5	10	0	0	2	2
Little Sand	3,009	100	117	205	151	14.3	6	2	0	0	0
Valleywood	1,455	100	103	170	131	10.5	7	4	0	2	4

[a] *Columnaris* infection was the primary cause of sickness and death of Eagle Lake fish.

Table 19. Elysian Lake harvest rate estimates.

Species	1987-88 Number per hour	1987-88 SE	1988-89 Number per hour	1988-89 SE	1989-90 Number per hour	1989-90 SE	1990-91 Number per hour	1990-91 SE
Summer angling								
Northern pike			0.027	0.003	0.008	0.001	0.002	0.001
Bullhead[a]			0.063	0.021	0.553	0.132	5.366	0.585
White bass			0.001	<0.001	0.003	0.001	0.001	0.001
Bluegill			0.002	0.002	0.001	0.001	0.011	0.011
Largemouth bass			0.008	0.002	0.008	0.002	0.003	0.002
Crappie[b]			0.007	0.002	0.060	0.012	0.086	0.035
Yellow perch			0.003	0.001	0.001	0.001	0.003	0.002
Walleye			0.072	0.014	0.071	0.008	0.009	0.002
All species			0.184	0.026	0.706	0.125	5.481	0.597
Winter angling								
Northern pike	0.045	0.008	0.020	0.003	0.003	0.001	0.000	0.000
White bass	0.000	0.000	0.000	0.000	<0.001	<0.001	0.000	0.000
Crappie	0.000	0.000	0.007	0.002	0.042	0.013	0.000	0.000
Yellow perch	0.016	0.005	0.002	0.001	<0.001	<0.001	0.000	0.000
Walleye	0.090	0.011	0.077	0.009	0.049	0.007	0.000	0.000
All species	0.151	0.016	0.107	0.010	0.095	0.015	0.000	0.000
Winter spearing								
Northern pike	0.326	0.032	0.000	0.000	0.031	0.029	0.000	0.000
Walleye	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
All species	0.327	0.032	0.000	0.000	0.031	0.029	0.000	0.000

[a]Primarily black bullhead.
[b]Black crappie and white crappie.

Walleye was the major species harvested by anglers on Elysian Lake during the 1988-89 fishing season when it accounted for 48% of the total harvest (Table 20) and 53% of the total yield (Table 21). Together walleye and northern pike (16 and 33%, respectively) accounted for 64% of the harvest and 86% of the yield. Bullhead (25 and 9%, respectively) accounted for most of the remainder. During the 1989-90 season, the walleye harvest declined 28%, and, because of the increase in bullhead (73% of the harvest), accounted for only 13% of the harvest. The northern pike harvest, which declined 79% from the previous season, accounted for only 1% of the harvest. At 43% of the 1989-90 yield, walleye still dominated in that category. Bullhead accounted for 34% of the yield and northern pike 9%. Another major change was a substantial increase in the number of harvested crappies.

In the 1990-91 season, the walleye harvest declined another 84%, and the northern pike harvest another 83%. Together they accounted for 0.2% of the total harvest. Bullhead accounted for 98% of the harvest in the 1990-91 season. Through an unfortunate oversight, no bullhead were measured in 1990-91, and yield estimates could not be made. When an extrapolation is made from the 1989-90 bullhead number-weight ratio, bullhead accounted for 95% of the yield. Under the same scenario, walleye and northern pike together accounted for 1.5%.

Results of an annual walleye and northern pike fishing tournament on Elysian Lake also attested to the collapse of the fisheries for those species (Table 22). Declines of 94% for walleye and 98% for pike in numbers reported per contest hour were nearly identical to the trends in annual harvest over two fishing seasons. The near total collapse of the pike fishery a year earlier than that seen in the walleye fishery was evident also.

Until the population collapse in 1990, the 1986 year class was dominant in the walleye harvest from Elysian Lake (Table 15). At age 2, it comprised 45% of the harvest during the 1988-89 fishing season, and at age 3, it comprised 40% of the 1989-90 harvest. However, it comprised only 10% of the winter 1989-90 harvest, as the 1987 year class emerged as

Table 20. Elysian Lake harvest estimates.

Species	1987-88 Number	1987-88 SE	1987-88 Number per hectare	1988-89 Number	1988-89 SE	1988-89 Number per hectare	1989-90 Number	1989-90 SE	1989-90 Number per hectare	1990-91 Number	1990-91 SE	1990-91 Number per hectare
Summer angling												
Northern pike				1,179	261	1.5	292	65	0.4	61	35	0.1
Bullhead[a]				2,751	840	3.6	21,282	5,649	27.7	167,639	26,579	218.5
White bass				36	16	<0.1	110	52	0.1	0	0	0.0
Bluegill				106	95	0.1	45	28	0.1	343	333	0.4
Largemouth bass				358	104	0.5	326	91	0.4	108	50	0.1
Crappie[b]				292	81	0.4	2,307	526	3.0	2,693	1,171	3.5
Yellow perch				148	56	0.2	49	20	0.1	87	48	0.1
Walleye				3,138	958	4.1	2,719	450	3.5	297	77	0.4
All species				8,008	1,633	10.4	27,130	5,742	35.4	171,228	27,202	223.2
Winter angling												
Northern pike	673	137	0.9	570	86	0.7	73	23	0.1	0	0	0.0
White bass	0	0	0.0	0	0	0.0	10	9	<0.1	0	0	0.0
Crappie	0	0	0.0	209	59	0.3	945	291	1.2	0	0	0.0
Yellow perch	240	79	0.3	59	27	0.1	8	8	<0.1	0	0	0.0
Walleye	1,335	209	1.7	2,156	281	2.8	1,088	163	1.4	0	0	0.0
All species	2,248	327	2.9	2,994	332	3.9	2,124	349	2.8	0	0	0.0
Total angling												
Northern pike				1,749	275	2.3	365	69	0.5	61	35	0.1
Bullhead				2,751	840	3.6	21,282	5,649	27.7	167,639	26,579	218.5
White bass				36	16	<0.1	120	53	0.2	0	0	0.0
Bluegill				106	95	0.1	45	28	0.1	343	333	0.4
Largemouth bass				358	104	0.5	326	91	0.4	108	50	0.1
Crappie				501	100	0.7	3,252	601	4.2	2,693	1,171	3.5
Yellow perch				207	62	0.3	57	22	0.1	87	48	0.1
Walleye				5,294	998	6.9	3,807	479	5.0	297	77	0.4
All species				11,002	1,666	14.3	29,254	5,753	38.1	171,228	27,202	223.2
Winter spearing												
Northern pike	1,554	277	2.0	0	0	0.0	6	6	<0.1	0	0	0.0
Walleye	6	5	<0.1	0	0	0.0	0	0	0.0	0	0	0.0
All species	1,560	277	2.0	0	0	0.0	6	6	<0.1	0	0	0.0

[a]Primarily black bullhead.
[b]Black crappie and white crappie.

Table 21. Elysian Lake yield estimates.

	1987-88			1988-89			1989-90			1990-91		
Species	Kg	SE	Kg per hectare	Kg	SE	Kg per hectare	Kg	SE	Kg per hectare	Kg	SE	Kg per hectare
Summer angling												
Northern pike				1,328	414	1.7	440	149	0.6	115	87	0.1
Bullhead[a]				644	236	0.8	2,434	350	3.2	19,173[b]	NA[c]	25.0
White bass				19	9	<0.1	60	32	0.1	19	14	<0.1
Bluegill				17	16	<0.1	10	7	<0.1	7	7	<0.1
Largemouth bass				152	68	0.2	186	59	0.2	49	23	0.1
Crappie[d]				51	12	0.1	530	140	0.7	609	65	0.8
Yellow perch				30	13	<0.1	21	12	<0.1	21	12	<0.1
Walleye				2,039	1,128	2.7	2,104	803	2.7	185	94	0.2
All species				4,280	1,227	5.6	5,786	902	7.5	20,178	NA	26.3
Winter angling												
Northern pike	781	236	1.0	918	322	1.2	229	103	0.3	0	0	0.0
White bass	0	0	0.0	0	0	0.0	6	6	<0.1	0	0	0.0
Crappie	0	0	0.0	43	7	0.1	118	15	0.2	0	0	0.0
Yellow perch	65	24	0.1	13	10	<0.1	2	2	<0.1	0	0	0.0
Walleye	976	347	1.3	1,533	1,010	2.0	989	420	1.3	0	0	0.0
All species	1,822	421	2.4	2,507	1,060	3.3	1,343	433	1.8	0	0	0.0
Total angling												
Northern pike				2,246	524	2.9	669	181	0.9	115	87	0.1
Bullhead				644	236	0.8	2,434	350	3.2	19,173	NA	25.0
White bass				19	9	<0.1	65	33	0.1	19	14	<0.1
Bluegill				17	16	<0.1	10	7	<0.1	7	7	<0.1
Largemouth bass				152	68	0.2	186	59	0.2	49	23	0.1
Crappie				94	14	0.1	648	141	0.8	609	65	0.8
Yellow perch				43	16	0.1	23	13	<0.1	21	12	<0.1
Walleye				3,572	1,514	4.7	3,093	906	4.0	185	94	0.2
All species				6,787	1,621	8.8	7,129	1,000	9.3	20,178	NA	26.3
Winter spearing												
Northern pike	1,804	563	2.4	0	0	0.0	19	21	<0.1	0	0	0.0
Walleye	4	5	<0.1	0	0	0.0	0	0	0.0	0	0	0.0

[a] Primarily black bullhead.
[b] Summer 1988 mean bullhead weight was used to calculate the 1989 yield.
[c] Not available.
[d] Black crappie and white crappie.

Table 22. Summary of fishing tournaments on Elysian Lake.

Number of participants	Total contest hours	Total catch: Walleye	Total catch: Northern pike
	21, 22 May 1988		
318	12	323	159
	20, 21 May 1989		
270	12	313	37
	19 May 1990		
202	6	9	2

Table 23. Distributions of summer boat and shore anglers on Madison and Elysian lakes.

Year	Angler hours: Boat	Angler hours: Shore[a]	Angler hours: Total	Percent boat	Percent shore
		Madison Lake			
1988	103,646	5,317	108,963	95.1	4.9
1989	94,197	3,362	97,560	96.6	3.4
1990	80,311	4,999	85,310	94.1	5.9
		Elysian Lake			
1988	38,064	5,480	43,544	87.4	12.6
1989	29,348	9,117	38,465	76.3	23.7
1990	14,132	17,111	31,243	45.2	54.8

[a] Includes all non-boat anglers.

dominant (53%). Winter anglers accounted for 41% of the total walleye harvest in 1988-89 and 29% in 1989-90. The dominance of the 1986 year class may have been the result of a large stocking in fall 1986 when nearly 94,000 fingerlings (1,075 kg) were released in Elysian Lake (Table 16). However, information on natural reproduction is unavailable, and it cannot be discounted. The near absence of age-2 walleye in the 1990-91 harvest indicated that the large 1988 fingerling stocking failed.

Mean total length of harvested walleye ranged from 400 mm during the 1988-89 season to 429 mm during the 1989-90 season (Table 14). The range in mean weights during those two seasons was 693-821 g. On average, winter anglers caught larger fish than summer anglers.

Elysian Lake has extensive shoreline available to summer anglers on the north and south shores. Shore angling, which was relatively unimportant in Madison Lake, became increasingly important in Elysian Lake throughout the study, and in 1990, it accounted for more than half the angling (Table 23). This change followed the trend of the bullhead fishery.

Discussion

Low recruitment appeared to be the chief cause of the steady population declines of age-4 and older walleye in Madison and Elysian lakes during the study. With the exception of the 1989-90 Elysian Lake mortality rates, annual mortality (0.39-0.48) and exploitation (0.25-0.38) did not appear to be excessively high compared to rates reported for other Minnesota walleye populations (Johnson and Johnson 1971; Schupp 1972; Johnson and Osborn 1977; Strand 1980; Thorn 1984; Osborn and Schupp 1985). Exploitation rates were generally high but within the reported range. Total mortality (0.75) and exploitation (0.50) of age-4 and older walleye in Elysian Lake in 1989-90 were remarkably high, and combined with low recruitment at all ages, led to the collapse of the walleye fishery. The winter fishery contributed substantially to annual exploitation on Elysian Lake but not on Madison Lake. Before the population collapse in Elysian Lake, winter angling accounted for 25-30% of the annual exploitation of age-4 and older walleye, while on Madison Lake, it accounted for only 1-5%.

The 1988 fall fingerling stockings in Madison and Elysian lakes yielded poor results. The low angler catch of age-2 walleye in 1990-91 suggested little contribution from nearly 27,000 fingerlings stocked in Madison Lake in 1988. Similarly, a stocking of more than 60,000 fingerlings in 1988 contributed almost nothing to the Elysian Lake fishery in 1990-91. The strong 1986 year class made large contributions to the fisheries of both lakes at age 2, and it seems likely that more walleye from the 1988 year class would have grown to sizes acceptable to anglers sometime during their third growing season had the stockings been successful.

Wide fluctuations in year class strength are common in walleye populations and have been attributed to a variety of biotic and abiotic factors (Koonce et al. 1977). Year class strength is frequently set during the first year of life, but abundance of fall fingerlings does not necessarily assure large numbers recruiting to the sport fishery (Carlander and Payne 1977; McWilliams and Larscheid 1992; Bandow and Anderson 1993). In Minnesota, walleye fingerling stocking is frequently conducted on a 2 or 3-year rotation basis. If stocking is done strictly for maintenance, and unless blank years are desired for evaluation of natural reproduction, fry stocking in years not scheduled for fingerling stocking may help to avoid several consecutive weak year classes should one or more fingerling stockings fail. In many cases, evaluations of such fry stockings may reveal that expensive fingerling stocking can be replaced by annual fry stocking. This was done successfully on Cannon River chain lakes (Gary Barnard, personal communication).

Angler success on Madison and Elysian lakes reflected trends in the strong 1986 year class. Summer harvest rates were similar on the two lakes at about 0.07 walleye/h in 1988 when the 1986 year class was newly recruited and abundant. Subsequently, rates declined sharply on Madison Lake to 0.04 and 0.02 walleye/h in 1989 and 1990, respectively. The 0.07 walleye/h rate was repeated on Elysian Lake in 1989, but dropped to 0.01 in 1990. Unweighted means over the three summers were 0.04 and 0.05 walleye/h on Madison Lake and Elysian lakes, respectively. These were similar to rates observed on eight lakes, with surface areas <500 hectares, in west-central Minnesota (Nelson 1983) and Pool 4 of the Mississippi River (Thorn 1984), but they were considerably below the 0.2 and larger walleye/h rates observed on the large walleye lakes in northern Minnesota (Johnson 1964; Schupp 1972; Strand 1980; Osborn and Schupp 1985; Payer et al. 1987). However, on Madison Lake, only 35% (on average) of the summer anglers were seeking only walleye.

Annual walleye yields from Madison Lake (and Elysian Lake before the population collapse) were relatively high. The annual yield from Madison Lake varied from 3.3 to 14.1 kg/hectare. The 3-year average of 8.4 kg/hectare ranked high compared with 48 North American lakes (Carlander 1977). Annual yields of 4.0 and 4.7 kg/hectare from Elysian Lake ranked higher than most Minnesota lakes above the 45th parallel (~St. Paul-Minneapolis).

In terms of size of harvested walleye, Madison and Elysian lakes provided relatively high quality fisheries. Mean weight of walleye harvested from Madison Lake ranged from 0.71 kg during the 1988-89 fishing season to 1.04 kg during the 1990-91 season. The unweighted mean was 0.88 kg. During the same period, Elysian Lake mean weights ranged 0.69-0.82 kg with an unweighted mean of 0.73 kg. The Madison Lake value is similar to the unweighted, 5-year mean of 0.87 kg (0.54-1.03 kg) observed from neighboring Francis Lake about 35 years earlier (Groebner 1960). These lakes compare well with northern Minnesota lakes where mean weights of harvested walleye are reported to have declined to about 0.5 kg in the 1970s and 1980s (Strand 1980; Osborn and Schupp 1985; Payer et al. 1987). Elysian Lake mean weights were similar to those observed for walleye in Pool 4 of the Mississippi River (0.65-0.80) (Thorn 1984).

In both study lakes, mean length at age exceeded those reported for walleye in Lake Sallie near Detroit Lakes and Lake of the Woods (Olson 1955; Payer et al. 1987). At age 4, Madison Lake walleye were about 2 years ahead of Lake Sallie walleye and about 4 years ahead of Lake of the Woods walleye. Ages at full maturity in Madison Lake were about 3 years for males and 4 years for females, whereas, in Lake of the Woods, all males were not mature until age 6, and all females until age 7. Madison Lake walleye appeared to reach full maturity at the same ages as walleye in Pool 4 of the Mississippi River (Thorn 1984) and Rathbun Lake, IA (Mitzner 1990). Thereafter, however, Madison Lake walleye grew slower than the latter populations with mean lengths about 1-2 years behind Pool 4 walleye and 1 year behind Rathbun Lake walleye.

Madison Lake walleye were heavier at length and longer at age than Elysian Lake walleye. The departure in mean length at age came primarily during the first or second year of life and may have been related to the size of stocked fingerlings. Although quantitative information is lacking, catch rates from past netting surveys indicate that Madison Lake has a larger abundance of yellow perch and greater abundance and diversity of cyprinid forage species than Elysian Lake (MNDNR lake survey files). The importance of gizzard shad in the diet of Madison Lake walleye is unknown. It is a preferred prey of Lake Erie walleye (Knight et al. 1984; Wolfert and Bur 1992), but in Madison Lake, the shad population appears to have wide swings in abundance because of occasional massive die offs in late fall. Walleye in relatively shallow Elysian Lake may be subject also to greater departures from optimum assimilation and growth temperatures.

Walleye yield from Madison Lake declined at a slower rate than the harvest because growth of the 1986 fish provided increasingly larger mean sizes of walleye to the creel. A late 1980's drought that seriously reduced spawning habitat, probably had a large role in the sharp decline of the northern pike harvest after 1988, and possibly influenced the walleye population.

Natural reproduction in 1986 was an important factor in the Madison Lake walleye fishery during this study. The 1986 year class comprised 58, 59, and 34% of the walleye harvest during the 1988-89, 1989-90, and 1990-91 fishing seasons, respectively. Natural reproduction contributed 65, 46, and 70% of those 1986 fish, respectively, while accounting for 38, 27, and 24% of the total walleye harvest, respectively. The harvest figures of naturally produced walleye represent a least case because some of those fish undoubtedly were supplanted by stocked fish. The true potential of natural reproduction in 1986 can only be contemplated.

The importance of natural reproduction in Madison Lake on a long term basis is unknown. Aside from those harvest figures for a single year class, information about walleye spawning activity is scant. The frequency and locations of successful spawning are unknown. Most of the lake has soft substrate near shore, but areas with rock and boulder substrate exist. The most productive sites for capturing mature walleye in spring were usually in or near those hard bottom areas.

A spring walleye run occurs in an inlet of Madison Lake when water levels are favorable, even though the gravel-rubble, hard-bottom substrate that is generally thought of in Minnesota as classic walleye spawning habitat probably does not exist upstream. However, such substrate is not a universal requirement. Priegel (1970) reported that walleye in the Fox and Wolf Rivers in Wisconsin spawn over flooded marsh vegetation. Holzer and Von Ruden (1982) confirmed that walleye spawned over reed canary grass in an off-channel area of the Mississippi River below Lock and Dam 7. MNDNR fisheries managers confirmed the same phenomenon below Lock and Dam 3 (MNDNR files). A recent electrophoresis study suggested that Mississippi River walleye below St. Anthony Falls are genetically divergent from walleye in northern Minnesota watersheds (McInerny et al. 1991). In the 1970s, offspring of walleye from the Mississippi River near Red Wing, MN were released in the management area that includes Madison Lake, but the exact disposition of those fish is unknown.

Low harvest of the 1987 year class at ages 2 and 3 indicated poor natural reproduction of Madison Lake walleye in 1987. However, that should not be surprising if contribution from the lake's inlet is essential, because it was nearly dry in spring 1987. Sites of successful spawning need to be identified so they can be protected and walleye access not obstructed.

For yellow perch, Hokanson (1977) described the optimal conditions for gonad maturation that terminated in spawning to be when the fish were exposed to temperatures $\leq 6°C$ for 185 d. Walleye may have similar requirements, and those may vary among genetic strains. The practice of annually releasing walleye adapted to northern Minnesota spawning conditions into southern Minnesota waters might be counterproductive if the goal is to produce a reproducing population, as it could impede adaptation of stocks to the southern climate and physical habitat.

The initial full scale operation of the Elysian Lake aeration system followed a partial winterkill in 1978 from which the walleye population sustained heavy losses. Subsequent walleye stocking was successful as the aeration system maintained favorable oxygen concentrations and probably prevented winterkill in 1979 (Bandow 1986). Routine oxygen testing results

(MNDNR files) indicate that aeration prevented winterkill at least twice during the 1980s. However, in 1988, a partial winterkill occurred in spite of the aeration system. This may have started the collapse of the walleye fishery, particularly if it affected future recruitment. Judging by dead fish observed after ice-out in 1988, largemouth bass and white bass were most affected, but some dead walleye were also seen.

The 1986 walleye year class provided substantial harvest for two angling seasons after the winterkill, but the harvest declined abruptly in 1990-91. The aeration system was not operated during the 1990-91 winter with the hope that extensive winterkill would occur. Although the kill of black bullhead and carp was less than desired, a walleye fry stocking in spring 1991 was successful, and by late summer 1992, a popular walleye fishery reappeared in Elysian Lake.

Compared with walleye, northern pike are quite resistant to low oxygen concentrations (Moyle and Clothier 1959). The decline in the pike fishery was probably a result of high exploitation and poor recruitment. The drought in the latter part of the 1980s obstructed pike spawning.

With one exception, this account of events in Elysian Lake is very similar to accounts before the aeration system was installed, and it probably exemplifies what should be expected from winter aeration in general. The one exception was that aeration prevented a popular sport fishery from ending abruptly with winterkill while fishing quality was still high.

Before the aeration system was installed, Elysian Lake was characterized as a "boom and bust" lake (Scidmore 1970b). Taking advantage of the void created by extensive winterkill and fast growth potential in these lakes, fisheries managers are usually able to rapidly create superb short-term sport fisheries by stocking walleye fry or centrarchid (usually crappie) broodstock. Eventually, extensive winterkill again eradicates game fish and large numbers of bullhead and carp, and allows the cycle to be renewed. However, intervening partial winterkills frequently eliminate game fish or severely reduce their numbers, and favor dominance by resistant black bullhead and carp. Aeration can be beneficial, as it was in Elysian Lake, in reducing the frequency of partial winterkills.

Practically all aerated lakes are of the "boom and bust" type, and aeration will not likely change that. Unless a majority of anglers prefer bullhead or carp fishing, it is counterproductive to operate aeration equipment when game fish populations are in the down side of a cycle. However, this frequently is the case because of reluctance by owners or operators (usually sporting groups or local governments) to temporarily discontinue their operations. The decision to discontinue operation on Elysian Lake had many critics.

Public expectations often are unrealistic when it is decided to aerate lakes that have repeatedly suffered major perturbations in the past. Many expect that eutrophic lakes with poorly balanced fish communities, heavily dominated by black bullhead and carp, will suddenly emerge as undefiled resources producing persistently high quality fisheries. Educational efforts should be made to moderate those expectations at the onset.

Management Implications

Compared with popular walleye lakes in central and northern Minnesota, Madison and Elysian lakes provided quality walleye fisheries in terms of yield and average size of harvested walleye. Attempts to improve size through regulation changes would likely demand large sacrifices from anglers with little chance of success.

Low recruitment was the primary cause of declining walleye fisheries in both lakes during the study. Heavy fingerling stockings in 1988 failed to fill much of the void left by the decline of the strong 1986 year class. In lakes where fingerling stocking is done on a rotational basis to maintain populations, fry stocking in years not scheduled for fingerling stocking may help to avoid several consecutive weak year classes. Evaluation of such fry stockings may reveal that expensive fingerling stocking is unnecessary in many cases.

The role of natural reproduction in maintaining populations and producing strong year classes is variable. An understanding of this variation could increase management efficiency. The extent of natural reproduction in stocked lakes should be evaluated and explained to anglers. Successful spawning sites need to be identified so they can be protected, and walleye access assured. This would increase the chance of a strong year class being produced. An understanding of variation in natural reproduction may ultimately allow managers to stock when conditions are favorable and to avoid stocking on top of strong year classes when competition is possible.

Strong effort should be made to educate the public about winter lake aeration and its implications to encourage realistic expectations and assure that systems are designed and operated for maximum effectiveness. Unless a majority of anglers prefer bullhead or carp fishing, it is counterproductive to operate aeration equipment when game fish populations are in the down side of a cycle.

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