Minnesota Department of Natural Resources
Investigational Report 563, April 2015

DEPARTMENT OF NATURAL RESOURCES

Evaluation of Walleye Stocking in 50 Minnesota Lakes

Bradford G. Parsons, Jeffrey R. Reed,
Vaughn A. Snook, David F. Staples, and Jason L. Vinje

Minnesota Department of Natural Resources
Division of Fish and Wildlife
Section of Fisheries
23070 North Lakeshore Drive
Glenwood, MN 56334

This project was funded in part by the Federal Aid in Sport Fish Restoration (Dingell-Johnson) Program.
Completion Report, Study 635, D-J Project F-26-R Minnesota.

INTRODUCTION

Managing walleye (*Sander vitreus*) populations through stocking is common in North America (Fenton et al. 1996). Furthermore, stocking walleye to enhance angling opportunities is an important, highly visible function of the Minnesota Department of Natural Resources (MNDNR) Section of Fisheries. Of the roughly 2,700 lakes with an approved lake management plan (MNDNR 1982), over 1,500 identified walleye as a species of primary or secondary management focus. Of these, walleye stocking occurs in over 1,000 lakes. The cost of the MNDNR walleye stocking program averaged nearly $3.4 million annually from 2006-2008 (MNDNR, unpublished data).

Data from the Minnesota lake survey database indicates that walleye stocking is most effective in lakes ranging in size from roughly 80 to 400 ha. Lakes larger than this range often support natural reproduction by walleye, meaning stocking would be supplemental and thus less likely to be successful (Laarman 1978; Parsons and Pereira 2001). Walleye stocking in smaller lakes is also less successful, possibly due to lack of adequate habitat or forage, or competition from other predators, specifically northern pike (*Esox lucius*) and largemouth bass (*Micropterus salmoides*).

Even in lakes within the 80 to 400 ha range, the most effective walleye stocking regime is still unknown. Although effective walleye stocking regimes have been determined for numerous individual lakes through the lake management planning process (MNDNR 1982), inconsistent stocking regimes (i.e., the occasional stocking of age 1 and older fish, only one effort with fry stocking, etc.) and inconsistent evaluation in many other lakes have resulted in no clear, broader scale answers. Fry are the most economical walleye stocking method. However, fisheries managers and the public have questioned the success of fry in these lakes due to suspected competition with, or predation by, abundant centrarchid populations. Therefore, evaluations of fry stockings in these lakes are rare. Small fingerling stocking has not been attempted in Minnesota for many years. However, public perception regarding perceived successes in neighboring states has raised the question about why small fingerlings are not used here. Additionally, we have little objective data regarding the current recommended large fingerling stocking rate of 0.9 kg/ha (Minnesota Department of Natural Resources 1996). Analyses using the statewide lake survey database suggests that large fingerling stocking rates above 0.7 kg/ha may not be necessary (Minnesota Department of Natural Resources, unpublished data). Consequently, we proposed this study to systematically evaluate walleye stocking regimes in moderate-sized lakes in lake classes 23, 24, 25, and 31 (Schupp 1992). Specifically, we evaluated the success of walleye stocked as fry, small fingerlings, and three densities of large fingerlings.

In Minnesota, walleye fry are stocked within 1 to 3 days after hatching. Small fingerlings are generally raised in drainable ponds and harvested and stocked in June at sizes ranging from 1,100 to 3,300 fish per kg (about 25-50 mm). Large fingerlings are raised extensively in small natural lakes and wetlands and harvested with trap nets and stocked in September and October at sizes generally ranging from 11 to 110 fish per kg (about 100-200 mm).

Previous studies in larger lakes and impoundments have compared the effectiveness of different stocking methodologies for increasing walleye populations. In East Okoboji Lake, Iowa, Larscheid (1995) stocked fry, small fingerlings, and large fingerlings in 1992 and 1993. Fry contributed over 50% of each year class, followed by large fingerlings (15-38%) and small fingerlings (13-18%). However, small fingerlings were more effective than fry in Lake Oahe, South Dakota (Fielder 1992), and more effective than fry or large fingerlings in two Missouri impoundments (Koppleman et al. 1992). Parsons and Pereira (2001) found no difference in year class strength from natural reproduction, fry stocking, or large fingerling stocking in three Minnesota lakes.

Information on stocking success for lakes in the size range used in this study is more limited. Olson et al. (2000) stocked fry (12,000/ha), pond-reared small fingerlings (50/ha; 43-51 mm at stocking in late June), and hatchery-reared large fingerlings (50/ha; 115-140 mm at stocking in mid-September) in the same year for four years

In four New York lakes ranging in size from 70 to 152 ha. Fry stockings were unsuccessful, comprising less than 0.7% of fall age-0 walleye. They found no overall difference in success of small fingerling or large fingerling stockings; small fingerlings were more successful in two lakes, while large fingerlings were clearly more successful in the other two lakes. Lucchesi (2002) evaluated annual fry (5,000/ha) and small fingerling (250/ha; 20-40 mm at stocking in early June) in eastern South Dakota lakes ranging in size from 101 to 548 ha. Fry and small fingerlings were each stocked in four different lakes. Gill net sampling showed that fry stocking, along with limited natural reproduction, produced quality (defined as at least 15 walleye per gill net) walleye populations in all four study lakes, whereas small fingerling stocking failed to produce quality walleye populations in the other four lakes. Kampa and Hatzenbeler (2009) found significantly higher electrofishing catch at age 1 for large fingerling stockings than for small fingerling stockings in 24 Wisconsin lakes.

Small and large fingerling stocking densities have varied widely among studies, ranging from 38 to 250 stocked per surface ha (McWilliams and Larscheid 1992; Fielder 1992; Koppleman et al. 1992; Larscheid 1995; Olson et al. 2000). The small fingerling stocking density selected for this study was 370 fish per littoral ha. This is generally higher than rates used in other studies, but is based primarily on successful results obtained in the Ely, Minnesota management area in the 1980's where 237 to 350 small fingerlings per littoral ha were stocked (J. Geis, MNDNR, personal communication). This rate is also consistent with current practices in surrounding states. Iowa and Wisconsin use a rate of 125 small fingerlings per surface hectare (Kampa and Hatzenbeler 2009 J. Larscheid, Iowa DNR, personal communication), and South Dakota uses 250 small fingerlings per surface hectare (Lucchesi 2002). Neighboring states use surface area rather than littoral area to determine stocking rates. The lake classes selected for this study average about 40% littoral area (Schupp 1992), which would equate to about 150 small fingerlings per surface hectare. This study presented a unique opportunity to objectively evaluate walleye stocking methods at a scale not previously attempted. The large number of lakes and random assignment of stocking methodology was intended to overcome the inherent heterogeneity among lakes, and allow us to make informed, scientific recommendations.

METHODS

The lake survey database and Area and Regional Fisheries Managers were consulted to select appropriate lakes. To balance the needs of broad application across the state with the need to account for the inherent variability among lakes, we elected to study 50 lakes in lake classes (Schupp 1992) 23, 24, 25, and 31 that ranged from roughly 80 to 400 ha (Table 1; Figure 1). The Minnesota statewide lakes database contained 334 lakes which met the lake class and size criteria. To minimize the confounding effects of walleye migration (Rasmussen et al. 2002) we eliminated lakes with substantial connections to other water bodies. Since nearly all Minnesota lakes have some connection to other bodies, this was by necessity subjectively accomplished with input from local personnel.

All lakes were stocked in 2001 and 2003, as indicated. Two lakes were randomly assigned to receive one of 25 stocking methodology combinations, where A = 2,500 fry/littoral ha (lha); B = 370 small fingerlings/lha; C = 0.45 kg large fingerlings/lha; D = 0.9 kg large fingerlings/lha; and E = 1.8 kg large fingerlings/lha. After determining that evaluation at this level was possible given personnel and financial considerations, a third stocking event was added for 2005. In 2005 ten lakes were randomly assigned to each of the five methods (A-E), without regard to prior method. Study lakes were not stocked in 2002, 2004, or 2006 to prevent possible year class suppression (Li et al. 1996) and to provide further evaluation of natural reproduction.

2001	A	A	A	A	A	B	B	B	B	B	C	C	C	C	C	D	D	D	D	D	E	E	E	E	E
2003	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E

TABLE 1. Lake name, identification number, fisheries management area, county, lake class, lake size in acres (Acres), lake size in hectares (Ha), littoral area in hectares (Litt ha), and stocking treatment for study lakes. Treatment A refers to fry, B to small fingerling, C to 0.45 kg/lha of large fingerlings, D to 0.9 kg/lha large fingerlings, and E to 1.9 kg/lha large fingerlings. First, second, and third letters of treatment refer to stocking completed in 2001, 2003, and 2005, respectively.

Lake	Lake ID	Area	County	Class	Acres	Ha	Litt ha	Treat
Gilbert	18-0320	Brainerd	Cass	25	369	149	91	AAA
Ruby	31-0422	Grand Rapids	Itasca	23	243	98	36	AAD
Elmo	82-0106	East Metro	Washington	23	206	83	18	ABE
Medicine	27-0104	West Metro	Hennepin	24	886	389	161	ABE
South Turtle	56-0377	Fergus Falls	Ottertail	25	630	255	160	ACD
Cedar	66-0052	Waterville	Rice	24	804	325	271	ACA
Sylvan	11-0304	Brainerd	Cass	25	803	325	148	ADD
Eagle	03-0265	Detroit Lakes	Becker	31	308	125	57	ADC
Juggler	03-0136	Detroit Lakes	Becker	23	365	148	60	AEE
Smith	21-0016	Glenwood	Douglas	31	575	233	109	AEB
Pickerel	03-0287	Detroit Lakes	Becker	25	332	134	50	BAC
Kings	73-0233	Montrose	Stearns	31	194	79	19	BAD
Fish	13-0068	Hinckley	Chisago	24	306	124	56	BBA
Deer	04-0230	Bemidji	Beltrami	31	262	106	48	BBD
East Silent	56-0517	Fergus Falls	Ottertail	23	310	125	23	BCA
Burgen	21-0049	Glenwood	Douglas	31	184	74	21	BCB
Clear	40-0079	Waterville	LeSeuer	24	268	108	80	BDB
Long	03-0383	Detroit Lakes	Becker	25	357	144	61	BDB
Balsam	31-0259	Grand Rapids	Itasca	25	710	287	119	BED
Blackwater	11-0274	Walker	Cass	25	722	292	137	BED
East Twin	26-0382	Fergus Falls	Ottertail	31	333	135	76	CAD
Scandinavian	61-0041	Glenwood	Pope	24	424	172	96	CAE
French	86-0273	Montrose	Wright	24	310	125	63	CBB
Horseshoe	04-0358	Walker	Cass	23	225	91	32	CBC
Vermont	21-0073	Glenwood	Douglas	25	314	127	83	CCB
Camp	76-0072	Spicer	Swift	24	203	82	39	CCE
Long	11-0142	Walker	Cass	25	926	375	144	CDE
Eagle	27-0111	West Metro	Hennepin	24	291	118	80	CDC
Johanna	62-0078	East Metro	Ramsey	24	200	81	40	CEB
Maple	77-0181	Little Falls	Todd	31	366	148	69	CEE
Rogers	18-0184	Brainerd	Crow Wing	23	219	87	33	DAC
George	34-0142	Spicer	Kandiyohi	31	231	93	45	DAB
Duck	29-0142	Park Rapids	Hubbard	31	326	132	61	DBE
Two Inlets	03-0017	Park Rapids	Becker	25	578	234	68	DBC
South Twin	04-0053	Bemidji	Beltrami	23	205	83	31	DCE
Beauty	77-0035	Little Falls	Todd	31	220	89	55	DCD
Rabbit	01-0091	Aitkin	Aitkin	23	214	87	31	DDD
Portage	56-0140	Fergus Falls	Ottertail	31	265	107	60	DDA
Johnson	31-0687	Grand Rapids	Itasca	23	305	123	36	DEC
Boot	03-0030	Park Rapids	Becker	23	348	141	38	DEA
Balm	04-0329	Bemidji	Beltrami	25	512	207	114	EAA
Linka	61-0037	Glenwood	Pope	31	197	80	31	EAB
Thistledew	31-0158	Grand Rapids	Itasca	23	318	129	29	EBB
Granite	86-0217	Montrose	Stearns	24	339	137	44	EBA
Pleasant	86-0251	Montrose	Wright	24	509	206	105	ECC
Volney	40-0033	Waterville	LeSueur	24	283	115	52	ECC
Beltrami	04-0135	Bemidji	Beltrami	25	543	219	121	EDA
Mule	11-0200	Walker	Cass	23	456	185	73	EDE
Fairy	77-0154	Little Falls	Todd	31	297	120	61	EEC
Long	27-0160	West Metro	Hennepin	24	261	106	53	EEA

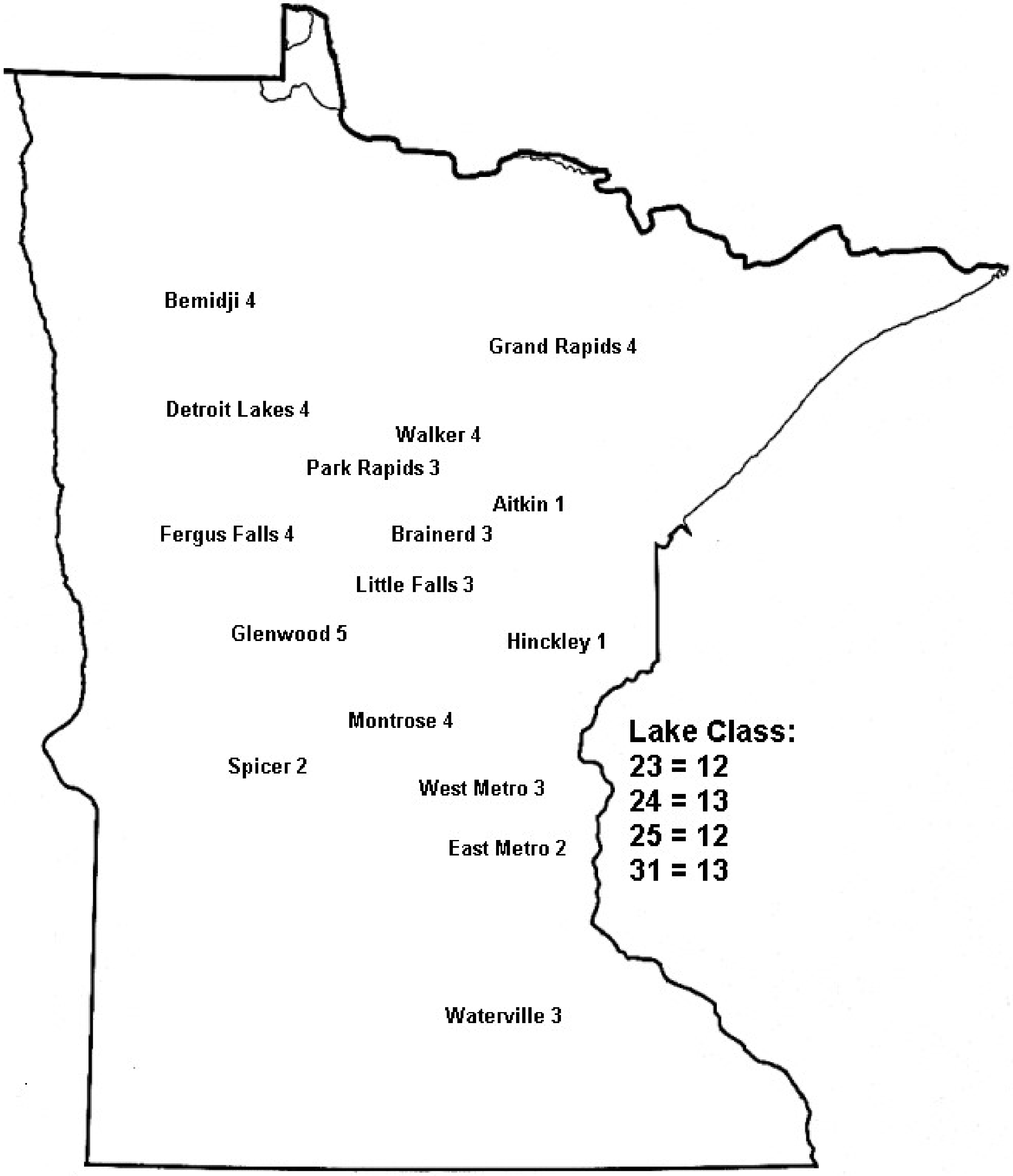


FIGURE 1. Distribution of study lakes by fisheries management area and lake class.

All walleye used in this study were marked as fry with a 6 hr oxytetracyline (OTC) immersion (Logsdon et al. 2004). Fish for the fry treatment were stocked by boat in the pelagic zone of the lake within 1 to 3 days after hatching, while fish for the small and large fingerling treatments were stocked into rearing ponds. Small walleye fingerlings were reared in ponds at the New London and Waterville hatcheries in Minnesota and the Blue Dog hatchery in South Dakota, with harvest occurring between mid-June and early July. Large walleye fingerlings were reared in numerous natural ponds using standard Minnesota procedures (Herwig et al. 2004), with harvest occurring in September and October using trap nets after water temperatures fell below 18°C. Both small and large fingerlings were stocked from shore at public access sites. Subsamples of stocked small and large fingerlings were collected to determine OTC efficacy.

All lakes were surveyed with experimental gill nets in 2004, 2006, and 2008, to target walleye at age-3. We selected gillnet catch per net at age 3 (GCPE-3) as our response variable because walleye at that age were fully recruited to the gill nets, yet not exposed to several possible years of angler exploitation. Nets were multifilament and 76 m long with five 15.2 m X 1.8 m panels of graded bar mesh sizes of 19, 25, 32, 38, and 51 mm. Nets were set overnight at historical locations in each lake; number of nets set ranged from 4 to 12 based on lake size and morphometry. Each walleye captured was measured (mm) and weighed (g), and all walleye <500 mm were identified by serial number, and frozen. When processed, scales and dorsal spines (Logsdon 2007) were removed for aging and otoliths were saved for OTC mark examination. Otoliths were stored in envelopes in a cool, dark location to prevent mark deterioration. The gill net samples also allowed the monitoring of the rest of the fish community, particularly yellow perch and northern pike, as explanatory variables in statistical analysis.

To collect young of the year, fall electrofishing was conducted on all fry and small fingerling stocked lakes in 2001 and 2003 during September or early October when water temperatures were between 10 and 20°C (Borkholder and Parsons 2001). We captured age-1 walleye using spring electrofishing was conducted from early May through early June on all study lakes in 2002, 2004, and 2006. If the entire shoreline including islands could be electrofished in under 2 hours, a full circuit was made. Otherwise, six 20 minute stations were randomly selected and held constant both fall and spring across years. All electrofishing was conducted at night with pulsed DC current, but given the large amount of lakes sampled, boats and crews varied considerably. All walleye were measured, weighed, and scale samples were taken to confirm age. A subsample of collected walleye were sacrificed and frozen to recover otoliths for OTC mark examination.

OTC mark examination began by removing the otoliths from the head of collected walleye. Otoliths were mounted on glass slides using cyanoacrylate glue. Slides were kept in the dark in slide trays until reading to prevent UV light from deteriorating the mark. Slides were examined under magnification after sanding with fine (800 grit) sandpaper. When a mark was detected it was graded for clarity and brightness. Grade III indicates a strong mark with a sharp outline and intense golden yellow color. Grade I indicates a mark lacking sharp outline with faint color.

The proportion of marked otoliths was used to adjust GCPE-3 values to account for natural reproduction in data analysis. If all fish were marked, the CPE value was used. If all fish examined were not marked, CPE was reduced. For example, if CPE was 4.0 and 75% of fish were marked, a CPE of 3.0 was used. However, occasional problems with marking efficacy required making assumptions regarding fish origin. Data were transformed as ln(CPE+1) to account for numerous zero values.

We fit a linear model (Kutner et al. 2004) to the age-1 electrofishing and age-3 gill net CPE data: $\log_e(\text{adjCPE}+1)_{ljki} = \text{Lake}_l + \text{Year}_j + \text{Treat}_k + e_i$, for lake l in year j at treatment level k = (A,B,C,D,E), and e_i assumed to be distributed as Normal(0,σ). We compared stocking treatments with the Tukey HSD multiple comparison method, which maintains a 95% family-wise confidence level for all mean comparisons among the 5 levels of stocking treatments (Kutner et al. 2004). To get estimates of the relative differences in CPE among the study lakes independent of year and treatment effects, we re-fit the linear models with lake as a random effect (Kutner et al. 2004), a so-called mixed effects model, in which the effects of the study lakes are assumed to be distributed as Normal($0,\sigma_L$). We report the among-lake variation in transformed CPE and the best linear unbiased predictors (BLUPs) of individual lake effects.

RESULTS AND DISCUSSION

OTC marking efficacy was generally good. For large fingerlings, 23 of 31 ponds checked for efficacy had 100% of fish with marks, and 3 of the 8 ponds containing unmarked fish (Morrison and Stony in 2001; Pond 12 in 2003) had less than 10% of fish without marks (Table 2). Of the five ponds with greater than 10% of the fish without marks, explanations existed for all but two ponds. The low mark incidence in Rehms Pond in 2001 (91.5% unmarked) was likely due to a large rain event which connected Rehms Pond to an adjacent pond which had been stocked with unmarked fry. Unmarked fish in Pond 13 (2003; 14.3% unmarked) and Pond 14 (2001; 28.6% unmarked), which were drainable ponds located at the Waterville hatchery, can likely be attributed to contamination by fry from the water source, Lake Tetonka (Logsdon 2006). We have no explanation for the poor marking results in Hagstrom (2001; 36.4% unmarked) or Anderson ponds (2005; 20.8% unmarked).

TABLE 2. Oxytetracycline mark efficacy from large fingerling rearing ponds. Grade III indicates a strong mark where Grade I indicates a very weak mark.

		OTC mark quality (%)			
Pond	Year	Grade III	Grade II	Grade I	No mark
Axberg	2001	12.5	37.5	50.0	0
Bird	2001	75.0	22.2	2.8	0
Hagstrom	2001	0	2.3	61.4	36.4
Morrison	2001	7.9	39.5	50.0	2.6
Pond 14	2001	61.5	8.8	1.1	28.6
Rehms	2001	2.1	2.1	4.3	91.5
Schriers	2001	25.0	75.0	0	0
Sloan	2001	83.7	16.3	0	0
Stony	2001	36.4	54.5	0	9.1
Axberg	2003	42.9	42.9	14.3	0
Roland	2003	80.0	20.0	0	0
Scharf	2003	50.0	50.0	0	0
Bountiful	2003	92.9	7.1	0	0
Pond 12	2003	66.7	26.7	0	6.7
Pond 13	2003	7.1	71.4	7.1	14.3
Malta	2003	10.7	78.6	10.7	0
Akron	2003	10.0	83.3	6.7	0
Kahler	2003	0	100.0	0	0
McCormic	2003	78.6	21.4	0	0
Danielson	2005	0	100.0	0	0
Reisdorph	2005	0	82.4	17.6	0
Anderson	2005	33.3	25.0	20.8	20.8
Dwyer	2005	75.0	25.0	0	0
Roland	2005	100.0	0	0	0
Bountiful	2005	12.5	87.5	0	0
Loon	2005	12.5	43.8	43.8	0
Lunde	2005	24.3	67.6	8.1	0
Big Olson	2005	0	0	100.0	0
Luneman	2005	0	0	100.0	0
Old Grade	2005	35.7	21.4	42.9	0
Schriers	2005	35.4	54.9	9.7	0

Incomplete marking efficacy posed several challenges when analyzing the data. For instance, in 2001 the Rehms Pond large fingerlings (91.5% unmarked) were stocked into Boot and Duck lakes , and along with Sloan Pond fingerlings (100% marked) into South Twin, Mule, and Long (W) lakes (Table 3). In Duck Lake, 8 of 9 (89%) gill net otoliths read were unmarked, very similar to the efficacy results from Rehms Pond (91% unmarked). That, along with virtually no natural reproduction observed in other stockings, led us to assign all walleye from the 2001 stocking in Duck Lake to stocking. In Boot Lake natural reproduction was very evident, and otoliths from the 2004 assessment were all unmarked, but based on the poor marking efficacy, we assigned the fish to stocking. For Long (W) Lake, the only gill net fish caught was marked. Both South Twin and Mule lakes received 20% of their large fingerlings from Rehms Pond and 80% from Sloans Pond. Although both South Twin and Mule lakes showed evidence of natural reproduction in the 2003 and 2005 stocking years (Table 4), a similar ratio of unmarked gill net otoliths to the Rehms/Sloan stocking proportion led to assigning all fish from the 2004 assessment to stocking in 2001. In Mule Lake, 4 of 13 (69%) of otoliths were unmarked, and in South Twin Lake 1 of 3 (33%) were unmarked.

TABLE 3. Large fingerling stocking and source pond of fingerlings in 2001, 2003, and 2005.

Lake	Year	kg	Number	Source Pond(s)	Treatment
Rabbit	2001	35	1,463	Schriers	D
South Twin	2001	35	1,182	Sloan, Rehms	D
Balm	2001	256	7,332	Axberg	E
Beltrami	2001	271	8,370	Stony, Sloan	E
Rogers	2001	38	1,577	Schriers	D
Johanna	2001	24	1,040	Hagstrom	C
East Twin	2001	43	1,900	Hagstrom	C
Portage	2001	66	2,920	Hagstrom	D
Vermont	2001	49	2,247	Bird	C
Scandinavian	2001	53	1,815	Morrison, Round, Bird	C
Linka	2001	75	3,320	Hagstrom	E
Johnson	2001	40	1,157	Axberg	D
Thistledew	2001	66	1,898	Axberg	E
Beauty	2001	63	2,622	Scriers	D
Fairy	2001	137	3,713	Schriers, Stony, Bird	E
Maple	2001	40	1,719	Schriers, Stony	C
French	2001	37	1,445	Hagstrom, Morrison	C
Granite	2001	100	2,860	Axberg	E
Pleasant	2001	234	6,695	Axberg	E
Boot	2001	44	1,746	Rehms	D
Two Inlets	2001	77	2,535	Sloan	D
Duck	2001	70	2,772	Rehms	D
Camp	2001	23	615	Hagstrom, Morrison	C

TABLE 3 continued.

Lake	Year	kg	Number	Source Pond(s)	Treatment
George	2001	51	1,792	Hanson	D
Eagle (WM)	2001	45	1,300	Axberg	C
Long (WM)	2001	107	3,920	Axberg, Hagstrom, Schriers	E
Mule	2001	165	4,695	Sloan, Rehms	E
Horseshoe	2001	18	918	Sloan	C
Long (Wa)	2001	80	600	Sloan, Rehms	C
Volney	2001	117	2,904	Pond 14, Schriers	E
Rabbit	2003	36	935	McCormic, Bountiful	D
South Twin	2003	17	380	McCormic	C
Beltrami	2003	256	3,080	McCormic	D
Sylvan	2003	163	10,440	Pond 13	D
Juggler	2003	135	2,980	Axberg	E
Eagle (DL)	2003	64	1,410	Axberg	D
Long (DL)	2003	69	1,520	Axberg	D
Johanna	2003	88	1,036	Malta, Akron	E
East Silent	2003	13	290	Axberg	C
South Turtle	2003	95	2,100	Axberg	C
Portage	2003	67	1,480	Axberg	D
Burgen	2003	15	340	Scharf, Rolland	C
Smith	2003	246	3,752	Malta, Akron, Bountiful, Rolland, Axberg	E
Vermont	2003	48	1,180	Scharf, Rolland, Bountiful	C
Johnson	2003	81	587	Malta	E
Balsam	2003	271	6,444	McCormic, Pond 12	E
Beauty	2003	32	700	McCormic	C
Fairy	2003	137	3,020	McCormic, Rolland	E
Maple	2003	154	3,400	Scharf, Rolland	E
Pleasant	2003	59	521	Malta, Kahler	C
Boot	2003	86	2,010	McCormic, Unmarked pond	E
Camp	2003	23	165	Malta	C
Cedar	2003	156	7,413	Malta, Pond 14	C
Clear	2003	88	1,854	Malta, Akron, Pond 5	D
Volney	2003	29	2,780	Ponds 2,5,7	C
Blackwater	2003	311	10,180	McCormic, Pond 12	E
Long (Wa)	2003	163	3,590	McCormic	D

TABLE 3 continued.

Lake	Year	kg	Number	Source Pond(s)	Treatment
Mule	2003	83	1,840	McCormic	D
Eagle (WM)	2003	91	1,080	Malta, Akron	D
Long (WM)	2003	119	1,284	Malta, Akron, Kahler	E
Elmo	2005	41	1,196	Dwyer, Anderson	E
Scandinavian	2005	217	12,100	New London, Golf Course, Danielson	E
Pleasant	2005	57	4,125	Reisdorph	C
Kings	2005	23	1,750	Danielson	D
Camp	2005	88	3,002	New London, Golf Course	E
Volney	2005	29	2,230	Toners	C
Eagle (WM)	2005	45	3,500	Danielson	C
Medicine	2005	362	22,070	Danielson, Golf Course, Reisdorph	E
Rabbit	2005	35	385	Schriers	D
Deer	2005	54	1,298	Old Grade	D
South Twin	2005	69	1,672	Old Grade	E
Rogers	2005	19	538	Douglas, Little Douglas	C
Sylvan	2005	166	2,424	Little Douglas, Schriers	D
Balsam	2005	137	10,872	Anderson	D
Ruby	2005	53	1,229	Dwyer	D
Fairy	2005	34	375	Schriers	C
Beauty	2005	62	685	Schriers	D
Maple	2005	154	3,549	Schriers, Bountiful, Toners	E
Two Inlets	2005	42	523	Big Olson, Luneman	C
Duck	2005	137	2,552	Big Olson, Luneman	E
Horseshoe	2005	18	640	Pond 13	C
Blackwater	2005	154	5,256	Old Grade, Anchor Hill, Ponds 12, 13, 14	D
Long (W)	2005	306	15,948	Anderson, Pond 12, Old Grade, Big Olson, Luneman, Dwyer	E
Mule	2005	165	5,737	Ponds 13, 14	E
Johnson	2005	21	1,575	Danielson	C
Pickerel	2005	29	717	Loon, Lunde	C
Eagle (DL)	2005	34	825	Lunde	C
Juggler	2005	133	7,832	Loon, Lunde, Anchor Hill	E
East Twin	2005	86	3,887	Loon, Lunde	D
South Turtle	2005	181	4,533	Loon, Lunde	D

TABLE 4. Observed GCPE-3 for walleye (Observed), GCPE-3 adjusted for natural reproduction (Adjust), and mean length (mm) at age 3 for the three stocked cohorts with stocking treatments (Treat).

	2004			2006			2008			
Lake	Observed	Adjust	mm	Actual	Adjust	mm	Observed	Adjust	mm	Treatment
Gilbert	0	0		0.11	0	356	0.11	0.11	408	AAA
Ruby	0.50	0	353	0	0		0.67	0.67	412	AAD
Elmo	0.83	0.8	414	0.33	0.33	416	1.33	1.33	407	ABE
Medicine	0	0		6.17	3.70	391	0.75	0.75	295	ABE
SouthTurtle	2.25	0.8	382	0.58	0.29	449	2.90	2.90	372	ACD
Cedar	0	0		0.10	0.10	315	0	0		ACA
Sylvan	0.08	0.0	401	0.33	0.33	404	0.75	0.75	422	ADD
Eagle (DL)	2.11	2.1	390	3.83	2.91	376	3.00	3.00	399	ADC
Juggler	2.33	2.3	402	1.11	0.62	407	6.89	4.89	361	AEE
Smith	0	0		0.67	0.67	353	0.14	0.14	427	AEB
Pickerel	1.44	0.7	335	3.33	3.00	412	5.89	1.06	305	BAC
Kings	0.83	0.5	370	0.33	0.17	462	2.67	2.16	325	BAD
Fish	0.11	0.1	353	0.56	0.56	480	0.22	0.22	479	BBA
Deer	0.33	0.3	377	0.33	0.33	393	0.50	0.50	364	BBD
East Silent	19.00	1.7	365	8.67	0.87	381	8.67	4.86	350	BCA
Burgen	0	0		0	0		0.50	0.50	390	BCB
Clear	0.17	0.1	375	0	0		0	0		BDB
Long (DL)	1.11	1.1	366	1.67	1.67	377	0	0		BDB
Balsam	0.36	0.3	347	0.33	0.33	351	0	0		BED
Blackwater	0.33	0.3	404	1.25	1.25	355	1.17	0.50	408	BED
East Twin	1.11	1.1	419	0	0		1.00	1.00	391	CAD
Scandinav	0.89	0.6	397	0.11	0	505	4.11	3.76	380	CAE
French	1.00	1.0	400	0.83	0.83	465	1.50	1.50	403	CBB
Horseshoe	7.67	1.5	371	2.67	1.01	382	8.33	1.42	368	CBC
Vermont	0.33	0.3	417	0	0		0	0		CCB
Camp	0	0		0	0		1.75	1.75	428	CCE
Long (W)	0.08	0.0	358	0.08	0.08	360	0.50	0.50	408	CDE
Eagle (WM)	0.17	0.1	315	2.17	2.17	405	0.50	0.50	329	CDC
Johanna	0.67	0.6		0.17	0.17	451	0.17	0.17	420	CEB
Maple	0.56	0.5	379	0.67	0.67	394	1.50	1.50	304	CEE
Rogers	0	0		0	0		0	0		DAC
George	1.40	1.4	345	1.00	1.00	438	0.20	0.20	469	DAB
Duck	1.89	1.8	388	1.89	1.89	429	6.00	6.00	411	DBE
Two Inlets	1.78	1.3	341	0.44	0.33	403	1.33	0.56	438	DBC
South Twin	0.50	0.5	429	0.83	0	343	1.17	0.83	324	DCE
Beauty	1.00	1.0	299	1.17	1.17	408	0.50	0.50	427	DCD
Rabbit	0.17	0.1	439	0.50	0.50	310	0.33	0.33	330	DDD
Portage	4.17	4.1	361	6.83	6.83	397	2.67	2.67	408	DDA
Johnson	0.33	0.3	364	0	0		1.00	1.00	308	DEC
Boot	2.56	2.5	391	2.33	1.17	431	1.00	0.33	406	DEA
Balm	2.00	1.6	323	1.78	1.78	406	0	0		EAA
Linka	0.33	0.3	411	0.33	0.33	491	1.83	1.83	463	EAB
Thistledew	0.11	0.1	392	1.00	0.78	369	3.56	3.56	398	EBB
Granite	0.17	0.1	435	0.17	0.17	431	1.50	1.50	470	EBA
Pleasant	1.89	1.8	398	1.33	1.33	419	1.33	1.33	405	ECC
Volney	1.17	1.1	381	0.67	0.67	404	0.89	0.89	352	ECC
Beltrami	1.78	1.2	325	1.33	1.33	328	1.56	0.67	358	EDA
Mule	1.56	1.5	365	0.56	0.18	431	0.56	0.34	403	EDE
Fairy	0.83	0.8	358	0.83	0.83	442	0.16	0.16	411	EEC
Long (WM)	0	0		1.17	1.17	367	0.33	0.33	333	EEA

Large fingerlings stockings from Hagstrom Pond in 2001 were also problematic. There was excellent production from that pond, and seven lakes received all or most of their large fingerlings from there (Table 3). In Portage (45% unmarked), French (50% unmarked), and Linka (67% unmarked) lakes (Johanna 75% unmarked; East Twin 60% unmarked) the proportion marked was similar to or higher than the efficacy results (36% no mark, 61% very poor mark), and since no natural reproduction was observed in any other year, all fish were considered stocked. Camp and Long (WM) also received large fingerlings from Hagstrom Pond in 2001, but no age-3 fish were captured in the 2004 gillnetting.

Large fingerlings stockings from Pond 14 in 2001, Pond 13 in 2003, and Anderson Pond in 2005 were not problematic. Pond 14 fish were stocked into Volney Lake in 2001, and all age-3 fish gillnetted in 2004 were considered stocked as only 2 of 10 (20%) otoliths were unmarked while 29% of efficacy fish were unmarked, and samplings in subsequent years provided no evidence of natural reproduction. Pond 13 fish were stocked in Sylvan Lake in 2003 and while 2 of the 4 age-3 fish gillnetted in 2006 were unmarked, they were considered stocked as samplings in surrounding years provided no evidence of natural reproduction. Anderson Pond fish were stocked into three lakes (Elmo, Balsam, and Long (W)) in 2005. Gillnetting in 2008 yielded no age 3 walleye for Balsam Lake, all 8 otoliths from Elmo Lake were marked, and earlier samples from Long (W) Lake provided no evidence of natural reproduction, so all age-3 gillnetted fish in 2008 were considered stocked.

Stocking quotas for fry and large fingerling were met in all years. However, there were several lakes in 2001 and 2003 where small fingerling quotas were not met (Table 5). In 2001, East Silent Lake received 47% of its quota and Burgen Lake received 35% of its quota. Furthermore, the Burgen Lake fish were not reared in the hatchery, but rather harvested from a fingerling rearing pond. These fish were also much larger than normal small fingerlings (264/kg). In 2003, four lakes received less than the prescribed full small fingerling quota: French (58%), Granite (76%), Medicine (63%), and Deer (59%).

TABLE 5. Fryling stocking quota, actual numbers stocked, source hatchery, and rate (number of fish per kg) in 2001, 2003, and 2005.

Lake	Year	Quota	Stocked	Source Hatchery	Rate
Deer	2001	17,700	17,700	Blue Dog	1543
Long (DL)	2001	22,800	22,800	New London	2433
Pickerel	2001	18,450	18,450	New London	2491
East Silent	2001	8,700	4,120	New London	2433
Burgen	2001	7,950	2,816	Bird Pond	254
Balsam	2001	44,400	44,400	Blue Dog, Waterville	1629
Fish	2001	21,000	21,000	New London	2427
Kings	2001	6,900	6,900	New London	2427
Blackwater	2001	50,850	50,850	Waterville	1808
Clear	2001	29,700	29,700	Waterville, New London	1808; 2427
Elmo	2003	6,750	6,750	Waterville	2776
Thistledew	2003	10,950	10,950	lew London	2304
Fish	2003	21,000	21,700	Blue Dog	3417
French	2003	23,400	13,620	New London	2304
Granite	2003	16,500	12,474	New London	2776
Two Inlets	2003	25,305	26,360	Blue Dog	3417
Duck	2003	22,650	23,250	Blue Dog	3417
Horseshoe	2003	12,000	12,400	Blue Dog	3417
Deer	2003	17,700	8,726	Waterville	1411; 750
Medicine	2003	59,850	32,434	Waterville	2776; 750
Johanna	2005	14,700	14,814	Waterville	2513
Linka	2005	11,700	11,867	New London	3843
French	2005	23,400	23,392	Waterville	2513
George	2005	16,800	17,593	New London	3558
Clear	2005	29,700	29,206	Waterville, New London	2138
Burgen	2005	7,950	9,376	New London	3843
Vermont	2005	31,050	31,500	Blue Dog	3086
Smith	2005	40,500	40,581	Blue Dog, New London	2756
Thistledew	2005	10,950	11,445	New London	3942
Long (DL)	2005	22,800	22,802	New London	3307

As with the large fingerlings, there were instances with unmarked efficacy fish for the small fingerlings (Table 6). These occurred for New London fish in 2001 and 2003 and Blue Dog fish in 2005. The 2005 Blue Dog fish were not a problem, because no fish were caught in Vermont Lake and the only fish from Smith Lake was marked. The 2001 New London fish were stocked in 5 lakes. Long (DL), Fish, and Clear lakes had marking efficacy similar to the 27% unmarked level or showed no evidence of natural reproduction in other years, so all fish were considered stocked. Pickerel and East Silent lakes showed natural reproduction in each year and had a low proportion of fish marked in the 2004 sampling. Thus we assigned 27% of the unmarked fish to stocking based on observed efficacy. The 2003 New London fish were stocked in three lakes. All otoliths from French and Granite lakes were marked. For Thistledew Lake, however, only 56% of otoliths were marked (and some natural reproduction was observed in other years), so 24% of unmarked fish were considered stocked for the observed efficacy.

Mean GCPE-3 and ECPE-1 (spring) were higher for the 2 higher density large fingerling stocking treatments after adjusting for natural reproduction (Figure 2). Actual and adjusted gill net and electrofishing catch for the stocked cohorts can be found in Tables 4 and 7, respectively. The linear model of transformed age-1 electrofishing CPE explained 65% of the variation in catch rates, though the majority of the variation was from large among-lake variation; there was approximately a 75% coefficient of variation (CV) for mean $\log_e$ adjusted age-1 electrofishing CPE among the study lakes (among-lake standard deviation σ_L = 0.66). The Tukey multiple comparisons of stocking treatments (Table 8) showed a highly significant (p = 0.003) increase in CPE for treatment D compared to treatment A and a moderately significant (p = 0.06) increase for treatment E (1.8 kg/lha fingerling) over treatment A. Treatments B and C were essentially identical, and neither showed a significant increase over treatment A. Estimated lake effects from the mixed effects model are given in Table 9.

TABLE 6. Oxytetracycline (OTC) mark efficacy from small fingerling hatcheries. Grade III indicates a strong mark where Grade I indicates a very weak mark.

		OTC mark quality (%)			
Hatchery	Year	Grade III	Grade II	Grade I	No mark
Blue Dog	2001	87.5	12.5	0	0
Blue Dog	2003	26.7	73.3	0	0
Blue Dog	2005	5.3	42.1	52.6	36.4
New London	2001	3.8	30.8	38.5	26.9
New London	2003	0	11.8	64.7	23.5
New London	2005	2.8	26.8	70.4	0
Waterville	2001	76.2	23.8	0	0
Waterville	2003	42.9	28.6	28.6	0
Waterville	2005	0	18.8	78.1	3.1

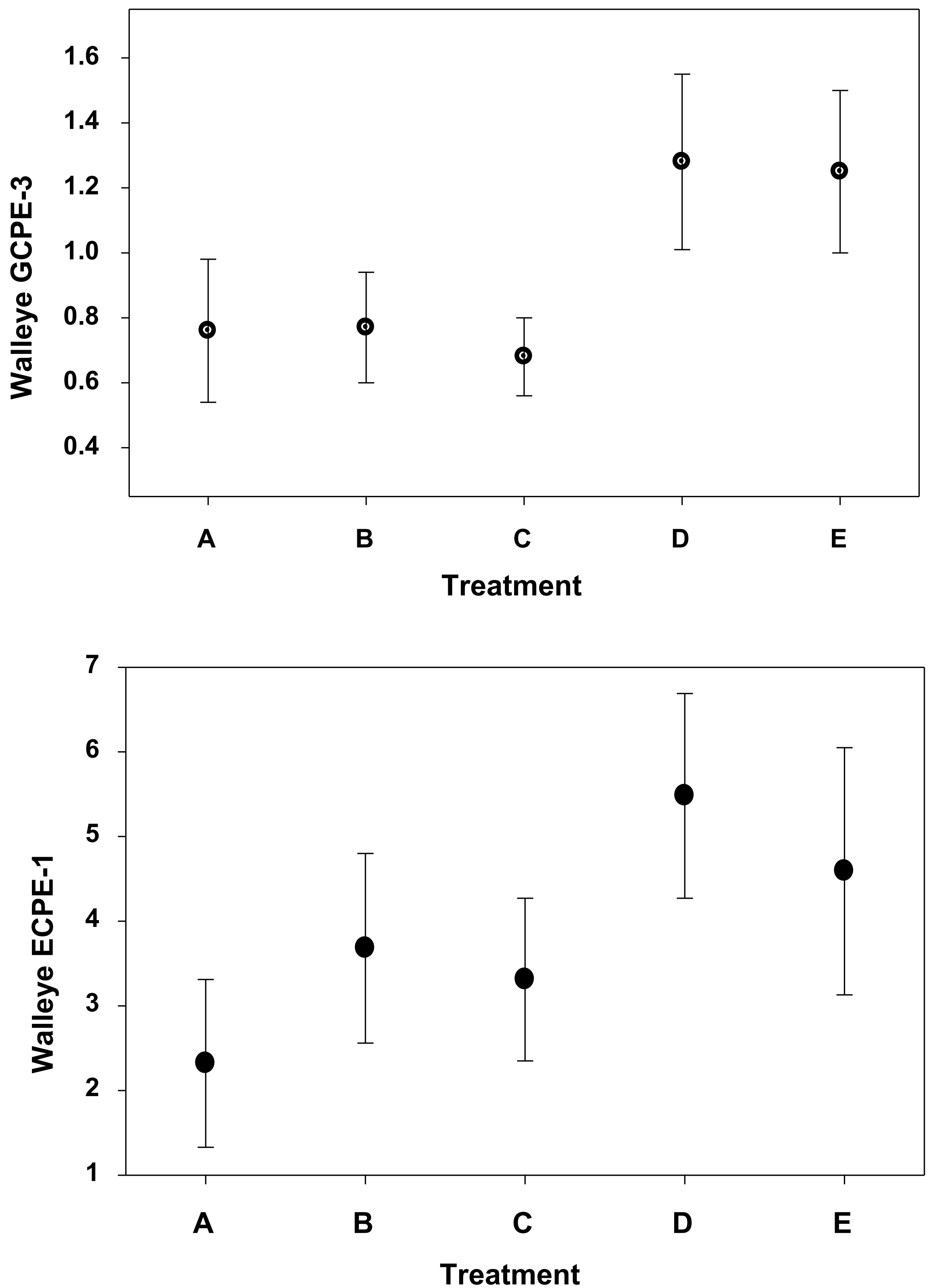


FIGURE 2. Mean walleye gill net CPE at age-3 and electrofishing CPE (number/hr) ± 1 se by stocking treatment adjusted for natural reproduction and prior to lake effect.

TABLE 7. Spring age-1 walleye electrofishing CPE (number/hour) and mean length for sampling in 2002, 2004, and 2006. Treatment letters refer to stocking in 2001, 2003, and 2005.

Lake	2002		2004		2006		Treatment
	CPE	Length	CPE	Length	CPE	Length	
Gilbert	0		0		0		AAA
Ruby	0		0		0		AAD
Elmo	0		0		2.5	172	ABE
Medicine	0		1.5	170	0.5	NS	ABE
South Turtle	1.0	193	0		10.0	181	ACD
Cedar	6.3	182	2.0	135	0.5	146	ACA
Sylvan	0		0.5	172	0.4	237	ADD
Eagle (DL)	5.0	196	0		0.5	172	ADC
Juggler	0		0.5	174	0		AEE
Smith	0		3.5	211	0		AEB
Pickerel	0		0		16.0	178	BAC
Kings	4.0	135	0		7.8	173	BAD
Fish	0		0		0		BBA
Deer	6.0	185	1.5	144	12.0	194	BBD
East Silent	7.5	180	52.0	199	12.0	177	BCA
Burgen	1.0	224	20.0	195	14.5	233	BCB
Clear	0		4.0	184	0		BDB
Long (DL)	0		0		0.5	202	BDB
Balsam	12.8	191	32.0	198	0		BED
Blackwater	2.0	177	3.5	177	19.5	152	BED
East Twin	1.0	170	0		16.0	155	CAD
Scandinavian	6.2	219	0		1.7	143	CAE
French	7.6	171	1.5	222	11.4	194	CBB
Horseshoe	4.0	171	7.4	188	65.0	156	CBC
Vermont	0.5	206	0.5	177	0		CCB
Camp	0		0		4.2	171	CCE
Long (W)	0		0.5	195	0.5	191	CDE
Eagle (WM)	5.0	NS	0		0		CDC
Johanna	6.3	167	7.0	214	0		CEB
Maple	1.0	151	0		5.5	178	CEE
Rogers	0.7	158	0		0.6	168	DAC
George	0.5	176	0		0		DAB
Duck	9.0	151	3.5	194	21.4	166	DBE
Two Inlets	9.0	160	0.5	175	19.5	212	DBC
South Twin	0		0		1.5	186	DCE
Beauty	1.0	154	0		10.0	231	DCD
Rabbit	15.5	176	2.5	165	4.0	223	DDD
Portage	11.4	183	25.0	191	10.9	203	DDA
Johnson	1.0	181	0		1.0	131	DEC
Boot	1.5	146	2.0	170	11.4	168	DEA
Balm	NS		0		0		EAA
Linka	21.1	177	26.0	185	24.7	178	EAB
Thistledew	1.5	180	0		16.0	171	EBB
Granite	0		0		0		EBA
Pleasant	0		0		0		ECC
Volney	0		5.0	149	0		ECC
Beltrami	NS		7.0	182	9.5	172	EDA
Mule	0		1.5	165	3.3	156	EDE
Fairy	2.5	190	3.8	205	0		EEC
Long (WM)	2.0	155	0		0		EEA

TABLE 8. Tukey HSD multiple comparisons of stocking treatment differences in $\log_e$ adjusted CPE+1 for age-1 electrofishing and age-3 gill net catch rates. Diff represents the difference in estimated stocking treatment means (adjusted for lake and year effects), LB and UB represent a 95% confidence interval for the difference, and *p* is the p-value for a 2-way test of H_o: Diff = 0.

	Treatment Comparisons, Age-1 EF				Treatment Comparisons, Age-3 GN			
Treat	Diff	LB	UB	*p*	Diff	LB	UB	*p*
B-A	0.36	-0.20	0.92	0.39	0.08	-0.18	0.35	0.91
C-A	0.37	-0.19	0.93	0.36	0.06	-0.20	0.33	0.96
D-A	0.75	0.19	1.32	0.00	0.28	0.02	0.55	**0.03**
E-A	0.56	-0.02	1.13	0.06	0.30	0.03	0.56	0.02
C-B	0.01	-0.55	0.57	1.00	-0.02	-0.28	0.25	1.00
D-B	0.39	-0.17	0.96	0.30	0.20	-0.06	0.47	0.23
E-B	0.20	-0.38	0.77	0.87	0.21	-0.05	0.48	0.17
D-C	0.38	-0.18	0.94	0.33	0.22	-0.05	0.48	0.16
E-C	0.19	-0.39	0.76	0.90	0.23	-0.04	0.50	0.12
E-D	-0.20	-0.77	0.38	0.87	0.01	-0.25	0.28	1.00

The linear model of transformed age-3 gill net CPE explained 61% of the variation in catch rates and the among-lake variation was lower with an approximate 25% CV for $\log_e$ adjusted age-3 gill net CPE among the study lakes (among-lake standard deviation = 0.27). The Tukey multiple comparisons among the stocking treatments (Table 8) showed significant increases in gill net CPE for treatments D and E over treatment A (*p* = 0.03 and 0.02, respectively); there was weak evidence for increases in CPE for treatments D and E compared to treatments B and C ($0.12 \le p \le 0.23$). Treatments B and C were again nearly identical, and neither showed a significant increase over treatment A. Estimated lake effects from the mixed effects model are given in Table 9; these are likely more reliable than the age-1 estimates because of the lower among-lake variation in the age-3 data.

Although each stocking method occasionally succeeded, the 0.9 and 1.8 kg/lha large fingerling stockings produced higher GCPE-3 and results were more consistent. Recently updated MNDNR walleye stocking guidelines recommend a primary stocking rate of 2 lbs/littoral acre (1.8kg/lha) for large fingerlings if stocking occurs every other year, as was the case in this study. However, we found no difference in performance between the 0.9 and 1.8 kg/lha large fingerling stockings. Furthermore, an overall analysis of stocking rates and gill net catch in Minnesota suggests that doubling the stocking rate from 0.9 to 1.8 kg/lha results in approximately 20% higher gill net catch of walleye in the future (MNDNR, unpublished data). Whether this translates to increased angler catch, and whether such an increase would even be noticeable by anglers is open to speculation. It is likely that financial or sociological factors, rather than the results of this or other biological studies, will dictate stocking rates in the near future.

TABLE 9. Best Linear Unbiased Predictors of Lake Effects on $\log_e$ adjusted CPE+1 from random effects linear models of age-1 electrofishing and age-3 gill net catch rates. Lakes marked with a * had relatively strong and consistent effects for the age-1 and age-3 samples.

	Lake Effect BLUPs		
Lake	Age1EF	Age3GN	Average
Balm	-0.41	0.12	-0.145
Balsam	0.68	-0.26	0.21
Beauty	-0.08	0.01	-0.035
Beltrami	0.5	0.09	0.295
Bergen	0.9	-0.21	0.345
Blackwater	0.54	-0.07	0.235
Boot	0.22	0.12	0.17
Camp	-0.36	-0.12	-0.24
Cedar	0.28	-0.23	0.025
Clear	-0.25	-0.31	-0.28
Deer	0.63	-0.14	0.245
Duck *	0.87	0.46	0.665
East Silent*	0.72	0.44	0.58
Eagle(DL)	-0.16	0.3	0.07
Eagle(WM)	-0.33	0.03	-0.15
East Twin	0.15	-0.01	0.07
Elmo	-0.31	0.04	-0.135
Fairy	-0.14	-0.09	-0.115
Fish	-0.48	-0.12	-0.3
French	0.72	0.17	0.445
George	-0.51	0.04	-0.235
Gilbert *	-0.45	-0.19	-0.32
Granite	-0.6	-0.06	-0.33
Horseshoe *	0.65	0.24	0.445
Johanna	0.26	-0.16	0.05
Johnson	-0.64	-0.18	-0.41
Juggler	-0.36	0.36	0
Kings	-0.09	0.03	-0.03
Linka	1.63	0.02	0.825
Long(DL)	-0.53	0.02	-0.255
Long(Walk)	-0.61	-0.26	-0.435
Long(WM)	-0.46	-0.14	-0.3
Maple	-0.2	0.01	-0.095
Medicine	-0.29	0.12	-0.085
Mule	-0.33	-0.14	-0.235
Pickerel	-0.08	0.28	0.1
Pleasant	-0.74	0.25	-0.245
Portage *	1.19	0.63	0.91
Rabbit	0.65	-0.26	0.195

TABLE 9 continued.

	Lake Effect BLUPs		
Lake	Age1EF	Age3GN	Average
Rogers *	-0.43	-0.31	-0.37
Ruby *	-0.58	-0.19	-0.385
S. Turtle	0.05	0.15	0.10
S. Twin	-0.58	-0.17	-0.375
Scandi	0.31	0.12	0.215
Smith *	-0.50	-0.19	-0.345
Sylvan	-0.55	-0.17	-0.36
Thistledew	0.33	0.12	0.225
Two Inlets	0.54	-0.01	0.265
Vermont *	-0.44	-0.22	-0.33
Volney	-0.33	0.07	-0.13

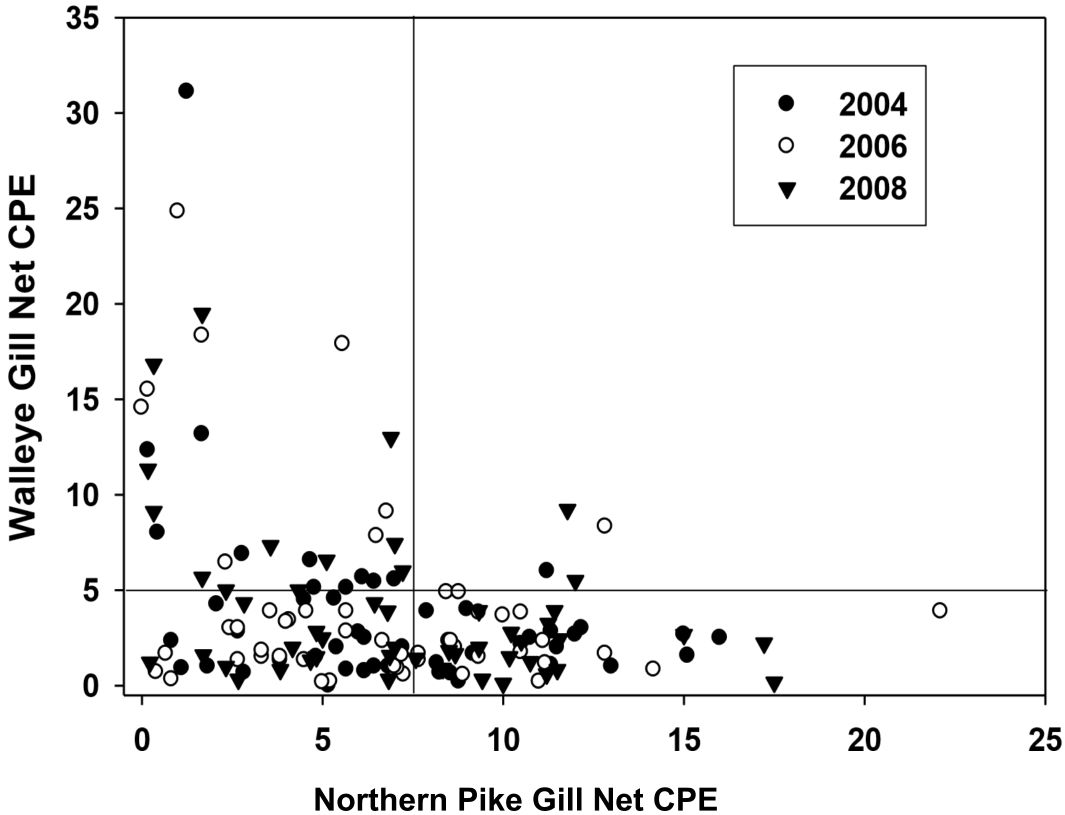
Regardless of stocking treatment, a walleye gill net catch of >5/net was very rare in study lakes with abundant northern pike (>7.5/net) (Table 10; Figure 3). Although slightly more common, a GCPE-3 of > 1 was also rare in lakes with abundant northern pike. We assumed that predation by northern pike was the likely reason for this, and it held true even when alternative prey such as yellow perch were abundant (>20/net) such as in Maple Lake and Eagle Lake (WM) (Table 10). It appears that an occasional successful year class can occur in the face of high northern pike abundance, but the relative consistency needed to achieve an overall walleye GCPE of > 5 is less likely. Fisheries managers need to take this into consideration when establishing management goals for walleye through the lake management planning process. Managers should also consider whether stocking relatively expensive large fingerlings into such situations is an appropriate management measure. Lakes with high northern pike numbers should be considered for larger carryover walleye, thus making available large fingerlings for lakes where success is more likely.

Small fingerling stocking was occasionally successful. However, there was no consistent lake attribute, either morphometric or biological, that we were able to identify that would predict where they would be most likely to succeed. For example, of the 6 stockings that produced GCPE-3 >1, two each were lake classes 23, 24, and 31. Although success was unlikely when northern pike gill net catch exceeded 7.5/net, this was also also the case with the other methods. However, three of the small fingerlings stockings where the quota of 370/lha was not met, East Silent, Medicine, and French lakes, were among the 6 small fingerlings stockings to produce GCPE-3 > 1. This suggests that if a lake is conducive to small fingerling stocking, then a lower stocking density may be feasible. Further research regarding the types of lakes that are conducive to this method and appropriate stocking density is warranted.

However, small fingerling stockings appeared more successful in this study than in three Wisconsin studies. Kampa and Hatzenbeler (2009) reported that small fingerling stockings in 5 of 12 (42%) lakes were undetectable with fall electrofishing at age-0, as were 40% of small fingerling stockings in a 4-year multilake study by Jennings et al. (2005), and 15 of 26 (58%) small fingerling stockings studied by Kampa et al. (2004). Fall electrofishing in this study failed to capture any fish in 7 of our 20 small fingerling stockings (35%) (note: no fall electrofishing for the 2005 stocking), and spring electrofishing failed to catch fish in 13 of 30 (43%) cases. In contrast, 25 of our 30 small fingerling stockings were detectable with gill nets at age 3. This suggests that gill nets are a more effective method of detecting presence and strength of a year class than either fall or spring electrofishing. Our modeling results also indicate the desirability of gill net data due to lower among-lake variation with the age-3 gill net data than with the age-1 spring electrofishing data.

TABLE 10. Total gill net CPE for walleye (WAE), northern pike (NOP), and yellow perch (YEP) for the study lakes in the 2004, 2006, and 2008 assessments.

	2004			2006			2008		
Lake	WAE	NOP	YEP	WAE	NOP	YEP	WAE	NOP	YEP
Gilbert	0.22	8.78	0	0.56	8.89	0	0.11	10.00	0.33
Ruby	2.83	11.33	2.83	1.33	7.67	2.33	2.00	9.33	2.83
Elmo	2.00	11.50	0.33	2.00	8.67	0	2.50	5.00	0.20
Medicine	1.08	11.33	14.58	7.83	6.50	15.50	3.92	9.33	5.83
South Turtle	4.25	2.08	0.08	3.42	4.08	0.75	3.90	6.80	0.50
Cedar	0.90	1.10	0.10	0.70	0.40	2.00	1.60	1.70	1.10
Sylvan	0.67	8.25	1.67	0.58	7.25	0.33	1.42	7.58	1.42
Eagle(DL)	6.56	4.67	7.33	8.33	12.83	NA	5.50	12.00	2.33
Juggler	4.56	5.33	0.56	4.89	8.44	2.22	9.22	11.78	3.44
Smith	1.56	15.11	22.56	3.00	2.44	30.78	1.57	6.86	31.29
Pickerel	5.11	5.67	1.00	17.89	5.56	3.22	13.00	6.89	5.11
Kings	2.33	8.50	21.00	3.33	4.00	47.50	4.33	2.83	39.00
Fish	1.00	6.44	0	3.89	3.56	0	0.89	8.33	0.33
Deer	1.00	6.83	0.67	1.67	7.67	2.17	1.50	10.17	2.33
East Silent	31.11	1.25	52.67	24.83	1.00	54.17	19.50	1.67	45.67
Burgen	0.67	2.83	0.33	1.33	2.67	2.00	1.00	2.33	2.83
Clear	2.83	2.67	14.50	0.33	0.83	22.17	0.33	2.67	39.33
Long(DL)	5.67	6.11	2.11	3.89	5.67	1.33	2.78	10.22	3.22
Balsam	0.64	8.55	5.64	0.92	7.08	3.42	0.33	9.42	1.42
Blackwater	1.67	9.17	2.83	3.83	10.50	2.08	3.92	11.42	2.17
East Twin	2.00	7.22	0.33	0.22	5.22	0.11	1.33	4.67	0
Scandinavian	2.67	15.00	6.44	2.33	8.56	4.11	6.00	7.22	18.22
French	1.50	4.83	40.33	1.50	3.33	8.33	2.00	4.17	4.67
Horseshoe	13.17	1.67	12.17	18.33	1.67	33.50	16.83	0.33	19.00
Vermont	0.83	5.67	0.33	0.20	11.00	1.60	0.83	11.50	0.17
Camp	2.50	10.75	15.25	1.75	10.50	29.50	3.25	11.25	17.00
Long(W)	0.75	6.17	2.83	0.83	14.17	1.50	1.25	10.75	0.75
Eagle(WM)	1.00	13.00	29.00	3.83	9.33	12.17	2.33	10.50	23.83
Johanna	1.33	3.83	74.67	1.50	3.83	21.67	1.50	4.83	15.33
Maple	4.00	9.00	58.22	1.00	7.00	44.56	1.83	8.50	49.00
Rogers	0	5.17	0	0.17	5.00	0	0.33	6.83	0
George	2.00	5.40	7.60	1.60	7.20	2.00	0.60	11.20	0.40
Duck	8.00	0.44	10.89	14.56	0	2.33	9.11	0.33	4.78
Two Inlets	5.11	4.78	24.78	4.89	8.78	13.56	6.56	5.11	14.22
South Twin	3.00	12.17	26.67	1.67	12.83	31.00	2.67	15.00	15.16
Beauty	2.17	10.50	37.33	3.67	10.00	2.33	2.00	7.00	3.33
Rabbit	1.00	1.83	3.50	1.33	4.50	1.33	0.83	3.83	0.67
Portage	12.33	0.17	1.50	15.50	0.17	4.00	11.33	0.17	2.17
Johnson	2.67	12.00	7.00	1.17	11.17	16.00	1.67	8.67	5.33
Boot	5.56	7.00	1.56	9.11	6.78	8.33	7.44	7.00	10.44
Balm	5.44	6.44	30.22	3.89	4.56	45.67	5.00	2.33	37.22
Linka	1.17	8.17	9.17	2.83	5.67	4.50	2.83	4.83	8.33
Thistledew	6.89	2.78	8.33	6.44	2.33	7.78	7.33	3.56	9.22
Granite	4.50	4.50	3.00	1.83	3.33	10.67	5.00	4.33	4.17
Pleasant	6.00	11.22	0.33	3.89	22.11	0.11	2.44	11.56	2.00
Volney	2.33	0.83	32.50	1.67	0.67	5.83	1.22	0.22	11.00
Beltrami	2.78	6.00	11.56	2.33	6.67	8.67	4.33	6.44	4.67
Mule	3.89	7.89	1.00	2.33	11.11	2.56	2.22	17.22	1.22
Fairy	2.50	16.00	0.17	1.50	9.33	1.33	0.17	17.50	0
Long(WM)	2.50	6.17	8.33	3.00	2.67	4.67	5.67	1.67	17.50



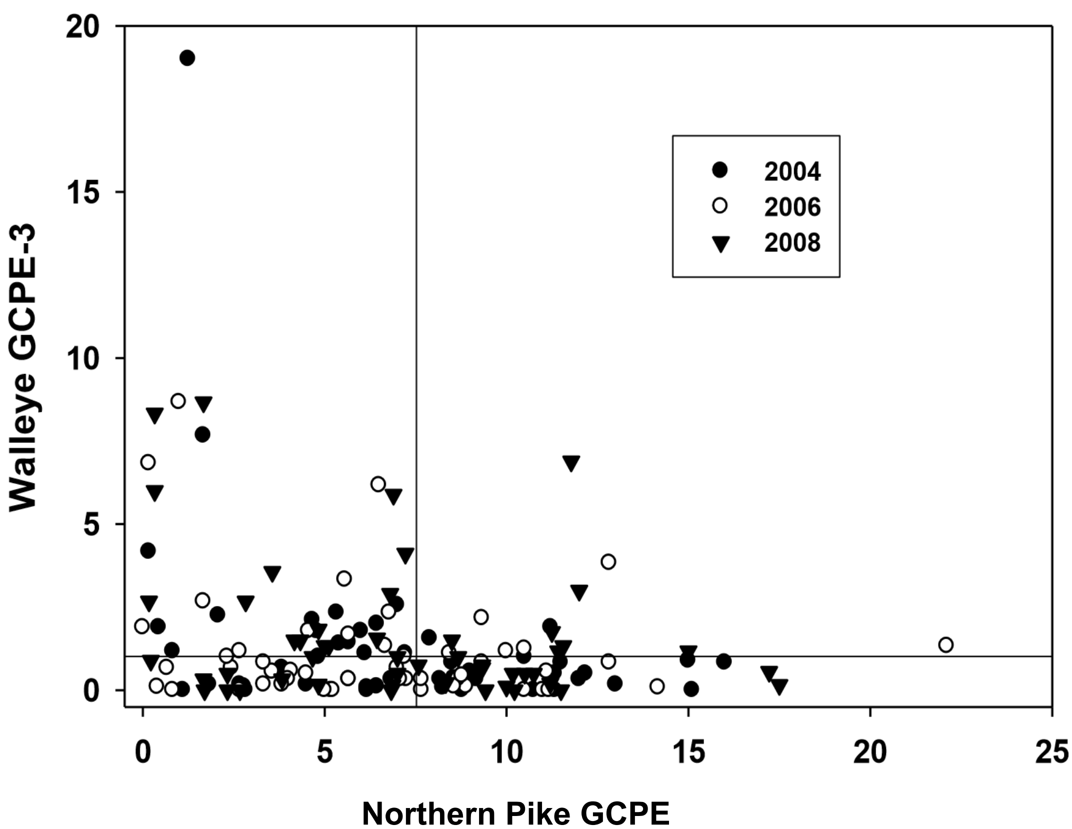


FIGURE 3. Total walleye gill net CPE and gill net CPE at age-3, by sampling year, versus northern pike gill net CPE. Vertical line represents the 7.5/net threshold for northern pike and horizontal line represents total walleye gill net CPE of 5.0 and age-3 gill net CPE of 1.0.

There were 13 instances where age-0 walleye were caught in fall electrofishing and then again the following spring as age-1 fish. In eleven cases, the mean length in spring was greater than in the fall (Table 11). This would be expected, given the common length-based overwinter mortality of age-0 walleye (Johnson et al. 1994). Mean length was equal in South Turtle Lake, but in Kings Lake the fall mean length (163 mm) was much higher than spring (135 mm). Furthermore, only 1 of 7 spring fish had an OTC mark, when 100% of the fall fish were marked. It is very likely that a local group, who were opposed to the project because it led to the denial of their private stocking permit, illegally stocked walleye fingerlings in the late fall of 2001.

Table 11. Fall age-0 walleye electrofishing CPE (number/hour), mean length, proportion OTC marked, and mean length of age-1 spring electrofishing for lakes stocked with fry and small fingerling in 2001 and 2003.

Lake	Year	Treatment	Catch Rate	Mean Length	% marked	Spring mm
Gilbert	2001	Fry	0			
Sylvan	2001	Fry	0			
Eagle(DL)	2001	Fry	4.0	176	0	196
Juggler	2001	Fry	0			
South Turtle	2001	Fry	0.5	193	Na	193
Smith	2001	Fry	0			
Ruby	2001	Fry	0			
Cedar	2001	Fry	9.0	163	88	182
Elmo	2001	Fry	0			
Medicine	2001	Fry	0			
Deer	2001	Sm. fingerling	0			185
Pickerel	2001	Sm. fingerling	0			
Long(DL)	2001	Sm. fingerling	9.5	175	80	
East Silent	2001	Sm. fingerling	110.5	165	41	180
Burgen	2001	Sm. fingerling	4.0	198	88	224
Balsam	2001	Sm. fingerling	0			191
Fish	2001	Sm. fingerling	0			
Kings	2001	Sm. fingerling	3.9	163	100	135
Blackwater	2001	Sm. fingerling	6.5	158	100	177
Clear	2001	Sm. fingerling	1.5	164	100	
Balm	2003	Fry	0			
Gilbert	2003	Fry	0			
Rogers	2003	Fry	0			
Pickerel	2003	Fry	0			
East Twin	2003	Fry	0			
Scandinavian	2003	Fry	0			
Linka	2003	Fry	12.0	183	100	185
Ruby	2003	Fry	0			
Kings	2003	Fry	0.9	178	100	
George	2003	Fry	0			
Deer	2003	Sm. fingerling	0			144
Elmo	2003	Sm. fingerling	0			
Thistledew	2003	Sm. fingerling	3.0	173	100	
Fish	2003	Sm. fingerling	0			
French	2003	Sm. fingerling	17.0	203	100	222
Granite	2003	Sm. fingerling	1.0	183	50	
Two Inlets	2003	Sm. fingerling	0.5	152	100	175
Duck	2003	Sm. fingerling	5.0	184	100	194
Horseshoe	2003	Sm. fingerling	20.0	174	83	188
Medicine	2003	Sm. fingerling	1.5	149	0	170

With such a large number of study lakes and the importance of the random lake effect in the modeling results, it is helpful to group the lakes based on similar overall stocking responses. The lakes in this study fell into seven broadly classified groups: 1) natural reproduction dominant; 2) all stocking events successful (GCPE-3 >1) ; 3) two out of three stocking events successful; 4) some natural reproduction, but stocking usually successful ; 5) one out of three stocking event successful; 6) one mediocre (GCPE-3 0.51-0.99) stocking event and two unsuccessful events; and 7) no successful stocking events (GCPE-3 <0.51/net).

Natural reproduction dominant

Four lakes, East Silent, Horseshoe, Pickerel, and Boot were dominated by natural reproduction (Figure 4). For the 2002, 2004, and 2006 year classes, when no stocking occurred, all four lakes showed moderate or strong year classes. Additionally, during the stocked years there were substantial numbers of unmarked fish sampled. These lakes had consistently high gill net catch, often exceeding 15 per net (Table 10). Stocking did contribute in these lakes as well, often exceeding 1 fish per gill net after adjustment (Table 4) with fry, small fingerling, and 0.45 kg/lha of large fingerlings as the stocking treatments. Boot Lake did receive treatments of 0.9 and 1.8 kg/lha of large fingerlings, but natural reproduction was still dominant. These lakes are excellent examples of small lakes with good water quality and obviously exceptional walleye habitat. All four lakes are relatively narrow water bodies, with high secchi depth readings, ranging from 4.5 m in Pickerel Lake to 6.1 m in Boot Lake, and, except for Pickerel Lake (class 25), are in lake class 23. East Silent and Horseshoe lakes had very few northern pike (<1.7/net), however northern pike were relatively abundant (>5.5/net) in Pickerel and Boot lakes.

Stocking always successful

Stocking was always successful in Duck, Portage, and Pleasant lakes (Figure 5), and all five stocking treatments were represented. Duck and Portage lakes were similar; both are class 31 lakes with very low northern pike (<0.5/net) abundance. Pleasant Lake (class 24), however, had very high northern pike catches (>11.0/net) including the highest northern pike GCPE observed in the study (22.11 in 2006) along with very low yellow perch GCPE (<2.1/net). Furthermore, two of the successful stockings were the 0.45 kg/lha treatment. This highlights the inherent variability among Minnesota lakes and demonstrates why the random lake effect was so important to our modeling results.

Two out of three successful stocking events

Five lakes, East Twin, French, George, Beauty, and Balm, produced two successful stocking results (Figure 6). The inconsistent performance of fry and small fingerling stockings is evident from this group. Of the six unsuccessful events, 2 were fry stockings and 3 were small fingerling stockings. However, fry and small fingerling stocking also each produced 2 of the successful events. Large fingerling stockings produced the other 8 successes and only one of the unsuccessful stockings. The 1.8 kg/lha treatment was underrepresented in this group, with only one of the 18 stocking events.

Some natural reproduction, but stocking usually successful

Another group of eleven lakes showed some evidence of natural reproduction, but stocking was often successful and produced the majority of fish. This group included Eagle (DL), Long (DL), South Turtle, Blackwater, Thistledew, South Twin, Beltrami, Mule, Juggler, Two Inlets, and Scandinavian lakes (examples in Figure 7). With the exception of Scandinavian Lake, all these lakes were in the northern half of the state and not in class 24. Again, each stocking treatment produced successful and unsuccessful results, but the 0.9 and 1.8 kg/la stockings provided the best results. With natural reproduction evident, it is logical to assume that fry stocking would perform better in this type of lake. Although sample size was small (5 fry stockings), two stockings produced year classes that met our successful category and two met the mediocre criteria.

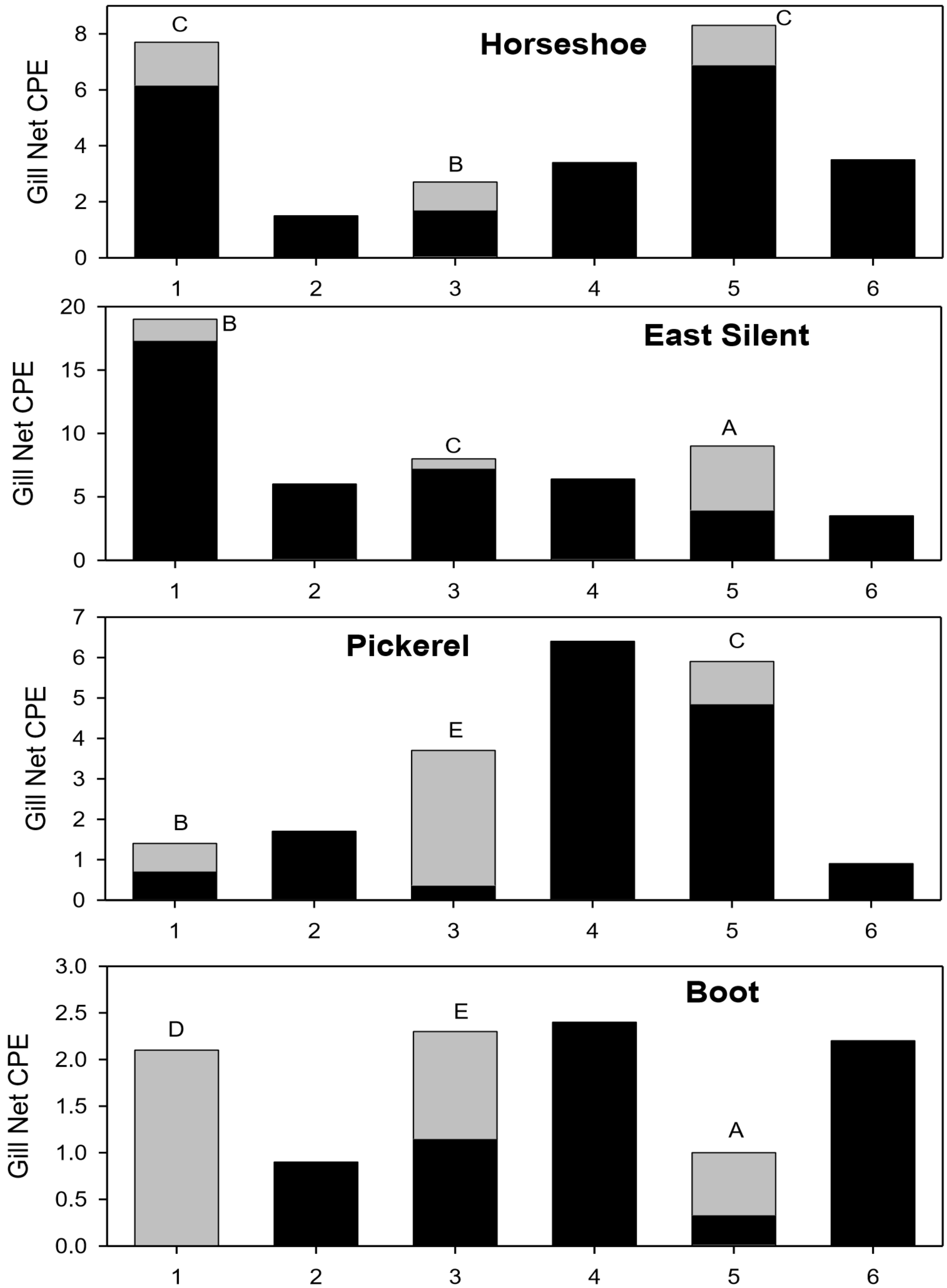


FIGURE 4. GCPE-3 of natural (black portion) and stocked (gray portion) walleye for the three stocked cohorts (2001, 2003, 2005) and three unstocked cohorts (2002 cohort is average of age 2 CPE in the 2004 survey and age 4 CPE in the 2006 survey; 2004 cohort is average of age 2 CPE in the 2006 survey and age 4 CPE in the 2008 survey; 2006 cohort is age 2 CPE in the 2008 survey) for Horseshoe, East Silent, Pickerel, and Boot lakes. Letters represent stocking treatment and x-axis represents the 2001-2006 cohorts.

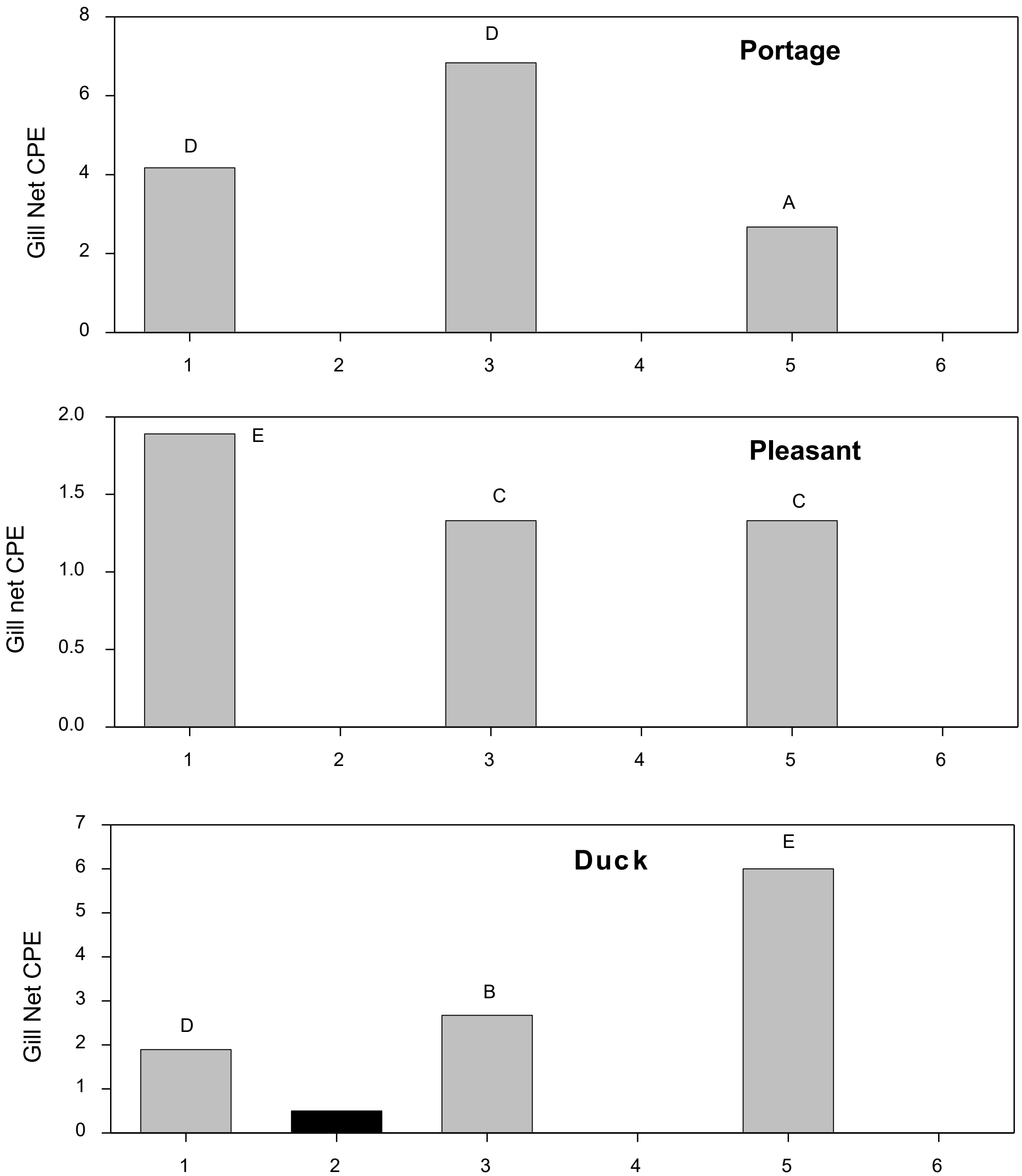


FIGURE 5. GCPE-3 of natural (black portion) and stocked (gray portion) walleye for the three stocked cohorts (2001, 2003, 2005) and three unstocked cohorts (2002 cohort is average of age 2 CPE in the 2004 survey and age 4 CPE in the 2006 survey; 2004 cohort is average of age 2 CPE in the 2006 survey and age 4 CPE in the 2008 survey; 2006 cohort is age 2 CPE in the 2008 survey) for Portage, Pleasant, and Duck lakes. Letters represent stocking treatment and x-axis represents the 20012006 cohorts.

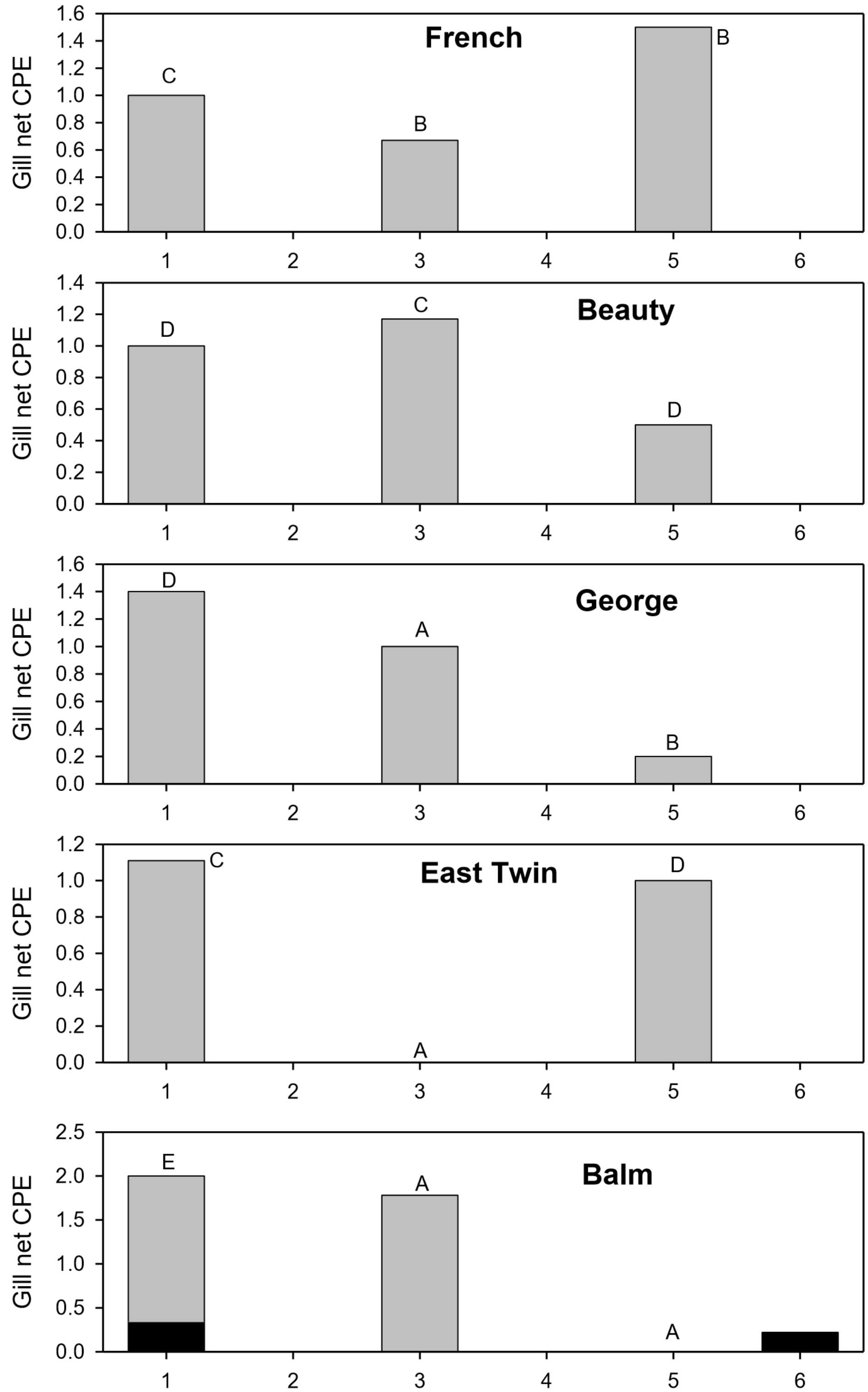


FIGURE 6. GCPE-3 of natural (black portion) and stocked (gray portion) walleye for the three stocked cohorts (2001, 2003, 2005) and three unstocked cohorts (2002 cohort is average of age 2 CPE in the 2004 survey and age 4 CPE in the 2006 survey; 2004 cohort is average of age 2 CPE in the 2006 survey and age 4 CPE in the 2008 survey; 2006 cohort is age 2 CPE in the 2008 survey) for French, Beauty, George, East Twin, and Balm lakes. Letters represent stocking treatment and x-axis represents the 2001-2006 cohorts.

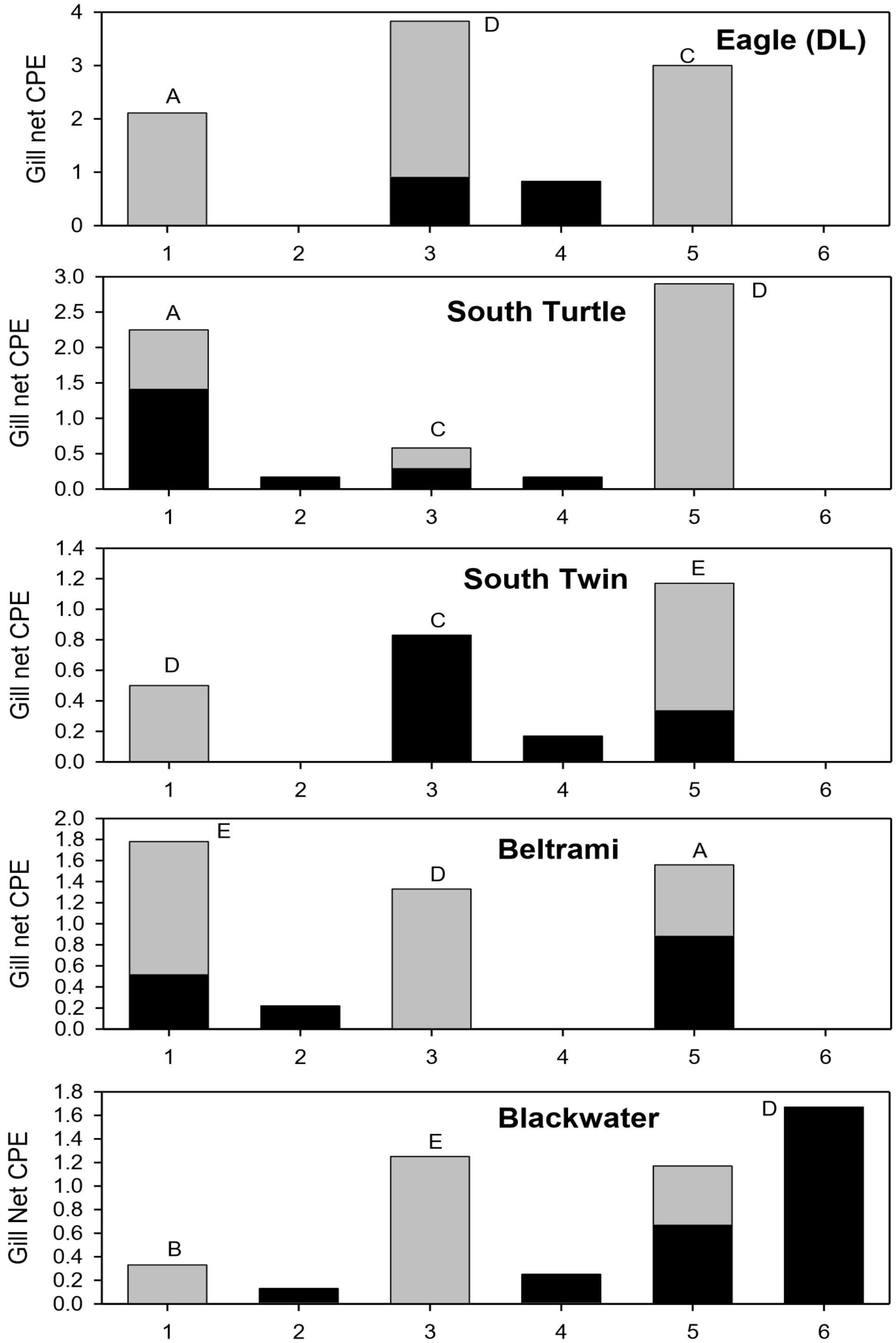


FIGURE 7. GCPE-3 of natural (black portion) and stocked (gray portion) walleye for the three stocked cohorts (2001, 2003, 2005) and three unstocked cohorts (2002 cohort is average of age 2 CPE in the 2004 survey and age 4 CPE in the 2006 survey; 2004 cohort is average of age 2 CPE in the 2006 survey and age 4 CPE in the 2008 survey; 2006 cohort is age 2 CPE in the 2008 survey) for Eagle (DL), South Turtle, South Twin, Beltrami, and Blackwater lakes. Letters represent stocking treatment and x-axis represents the 2001-2006 cohorts.

One out of three stocking events successful

Eleven lakes had one successful stocking event: Elmo, Medicine, Kings, Camp, Eagle (WM), Maple, Johnson, Linka, Granite, Volney, and Long (WM) (examples in Figure 8). Although generalizations for this group are difficult, these lakes did tend to have more success with the higher density large fingerling stockings. In five lakes (Elmo, Camp, Maple, Volney, and Long (WM)) the 1.8 kg/lha large fingerling stocking produced the successful result, while the 0.9 kg/lha large fingerling stocking produced the successful result in two lakes (Kings and Eagle (WM)). Fry and small fingerling treatments did however yield at least one successful stocking result. Both Medicine and Linka lakes had their best result with a small fingerling stocking and Granite Lake had a successful result with a fry stocking, despite 1.8 kg/lha large fingerling stockings in other years. An interesting marking efficacy dilemma was observed in Medicine Lake. The 2003 small fingerling stocking was extremely successful, but only 60% of otoliths examined from the 2006 gillnetting had an OTC mark despite all efficacy small fingerlings from that stocking being marked. No other evidence of natural reproduction was apparent during this study and the lake has no history of natural reproduction (MNDNR unpublished data).

One mediocre stocking event and two unsuccessful events

For five lakes, Ruby, Sylvan, Smith, Fish, and Johanna, all stocking events yielded a GCPE-3 <1 with only one GCPE-3 between 0.51-0.99. We also include Fairy Lake here, as it was the only lake in the study with two mediocre results. This group supports the modeling results showing better performance of the 0.9 and 1.8 kg/la stockings. Of the 18 stocking events, nine were fry or small fingerling stockings and only one of these, a small fingerling stocking in Fish Lake in 2003 produced a mediocre result. Large fingerling stockings (0.9 kg/lha in Ruby and Sylvan; 1.8 kg/lha in Smith and both Fairy cases; 0.45 kg/lha in Johanna) produced mediocre results in the other 6 cases. Higher density large fingerling stocking was not a guarantee, however, because in 2003 Sylvan Lake had a poor result with a 0.9 kg/lha stocking as did Johanna Lake with a 1.8 kg/lha stocking.

No successful stocking events

Ten lakes, including Rogers, Gilbert, Balsam, Clear, Cedar, Burgen, Deer, Rabbit, Long (W), and Vermont, had no successful stockings events. Of the 30 stocking events, only two were 1.8 kg/lha large fingerlings, while each of the other treatments were represented 6 or 8 times. The relationship between high northern pike abundance and poor stocking success generally held for this group. Five of the lakes (Gilbert, Balsam, Deer, Long(W), and Vermont) typically had northern pike GCPE > 7.5. Rogers Lake always had northern pike GCPE > 5 but never exceeded 7.5. Clear and Cedar Lakes in the Waterville area, Burgen in the Glenwood area, and Rabbit in the Aitkin area did not follow the walleye/northern pike relationship with northern pike GCPE typically less than 3 and always less than 4.

Linear modeling results and the individual lake descriptions from the stocking response groups show that the 0.9 and 1.8 kg/lha large fingerling stockings produced higher and more consistent GCPE-3 of walleye. Since large fingerlings have passed more life history bottlenecks than fry or small fingerlings, and the 0.45 kg/lha stockings introduce fewer fish, these results are not surprising. However, each method did have its advantages and successes, and simply stocking more large fingerlings did not assure a successful year class. Given the inherent variability among Minnesota lakes there will likely be no clear answer as to what is the ideal stocking methodology.

Fry stocking is inexpensive, and our results suggest that success can occur, usually in lakes that exhibit at least some natural reproduction. Results further indicated that of the four lake classes we studied classes 23 and 25 were better candidates for natural reproduction of walleye. Within lakes with excellent natural reproduction, our stocked fish did in fact survive, but their overall contribution to the population was relatively small.

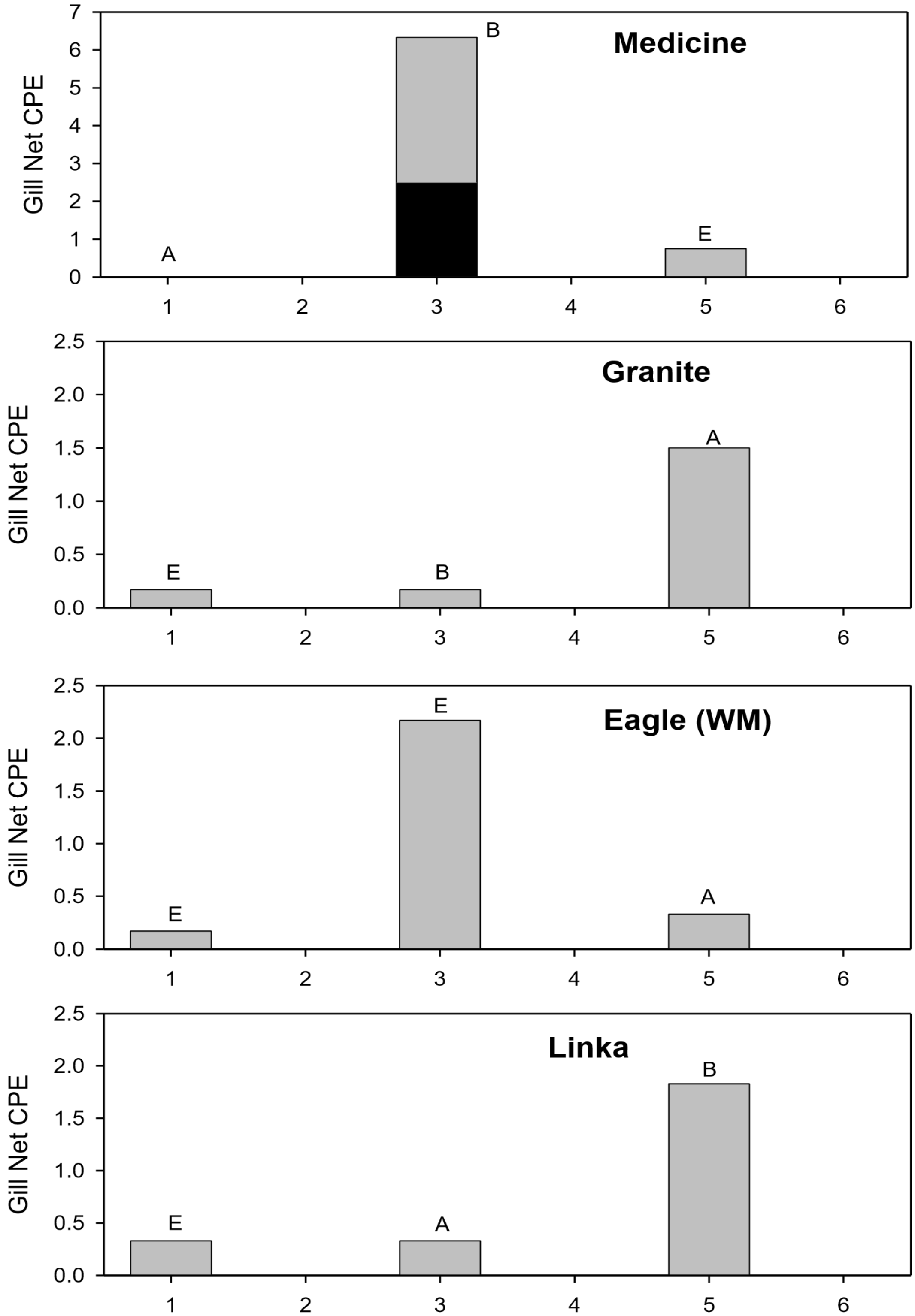


FIGURE 8. GCPE-3 of natural (black portion) and stocked (gray portion) walleye for the three stocked cohorts (2001, 2003, 2005) and three unstocked cohorts (2002 cohort is average of age 2 CPE in the 2004 survey and age 4 CPE in the 2006 survey; 2004 cohort is average of age 2 CPE in the 2006 survey and age 4 CPE in the 2008 survey; 2006 cohort is age 2 CPE in the 2008 survey) for Medicine, Granite, Eagle (WM), and Linka lakes. Letters represent stocking treatment and x-axis represents the 2001-2006 cohorts.

Natural reproduction was fairly common in our study lakes; four lakes were dominated by it over stocking. Reasonable amounts of natural reproduction occurred in another 11 lakes, but stocking was more responsible for walleye catches. Slight evidence of natural reproduction was observed in other lakes (i.e. Duck and Balm lakes), but aging errors could also lead to similar results.

Small fingerling stocking also appears to be a viable alternative in some lakes, but we were not able to determine guidelines as to which lakes are the best candidates. Small fingerlings also provide the advantage of being reared in a hatchery environment, which helps address concerns over Minnesota's extensive use of natural wetlands as rearing water (Norris 2007). The more controlled hatchery environment also reduces risks inherent to extensive rearing including invasive species and pathogens.

Gill nets were a better sampling tool than fall or spring electrofishing in this study. Stockings undetected by electrofishing at age-0 or age-1 were often detected, albeit often in low numbers, with gill nets when the walleye were age-3. However, electrofishing maintains the advantages of being non-lethal and able to identify year classes at least a year earlier than gill nets. Some lakes also appear to be difficult to gill net, but rather easy to electrofish. Burgen Lake, for instance had spring electrofishing catches of 20.0/hr in 2004 and 14.5/hr in 2006, but no fish caught in gill nets in 2006 and only 3 in 2008. Further examination of the relationship between electrofishing catch and eventual recruitment to older ages is warranted.

REFERENCES

Borkholder, B. D., and B. G. Parsons. 2001. Relationship between electrofishing catch rates of age-0 walleyes and water temperature in Minnesota lakes. North American Journal of Fisheries Management 21:318-325.

Fielder, D. G. 1992. Evaluation of stocking walleye fry and fingerlings and factors affecting their success in lower Lake Oahe, South Dakota. North American Journal of Fisheries Management 12:336-345.

Fenton, R., J. A. Mathias, and G. E. E. Moodie, 1996. Recent and future demand for walleye in North America. Fisheries 21(1):6-12.

Herwig, B. R., M. A. Hanson, J. R. Reed, B. G. Parsons, A. J. Potthoff, M. C. Ward, K. D. Zimmer, M. G. Butler, D. W. Willis, and V. A. Snook. 2004. Walleye stocking as a tool to suppress fathead minnows and improve habitat quality in semipermanent and permanent wetland in the prairie pothole region of Minnesota. Minnesota Department of Natural Resources Section of Fisheries Special Publication 159, St. Paul.

Jennings, M. J., J. M. Kampa, G. R. Hatzenbeler, and E. E. Emmons. 2005. Evaluation of supplemental walleye stocking in northern Wisconsin lakes. North American Journal of Fisheries Management 25:1171-1178.

Johnson, B. M., S. J. Gilbert, R. S. Stewart, L. G. Rudstam, Y. Allen, D. M. Fago, and D.

Dreikosen. 1994. Piscivores and their prey. Pages 319-352 in J. F. Kitchell, editor. Food web management: a case study of Lake Mendota, Wisconsin. Springer-Verlag, New York.

Kampa, J. M., M. J. Jennings, and G. R. Hatzenbeler. 2004. Short-term survival of small walleye fingerlings stocked into Wisconsin lakes. Pages 99-103 in M. J. Nickum, P. M. Mazik, J. G. Nickum, and D. D. MacKinlay, editors. Propogated fish in resource management. American Fisheries Society, Special Publication 44, American Fisheries Society, Bethesda, Maryland.

Kampa, J. M., and G. R. Hatzenbeler. 2009. Survival and growth of walleye fingerlings stocked at two sizes in 24 Wisconsin lakes. North American Journal of Fisheries Management 29:996-1000.

Koppelman, J. B., K. P. Sullivan, and P. J. Jeffries, Jr. 1992. Survival of three genetically marked walleyes stocked into two Missouri impoundments. North American Journal of Fisheries Management 12:291-298.

Kutner, M.H., Nachtsheim, C.J., and Neter, J. 2004. Applied Linear Regression Models (4th edition), McGraw-Hill/Irwin, New York.

Laarman, P. W. 1978. Case histories of stocking walleyes in inland lakes, impoundments, and the Great Lakes – 100 years with walleyes. Pages 252-260 in R. L. Kendall, editor. Selected coolwater fishes of North America. American Fisheries Society, Special Publication 11, Bethesda, Maryland.

Larscheid, J. G. 1995. Development of an optimal stocking regime for walleyes in East Okoboji Lake, Iowa. American Fisheries Society Symposium 15:472-483.

Li, J., Y. Cohen, D. H. Schupp, and I. R. Adelman. 1996. Effects of walleye stocking on year class strength. North American Journal of Fisheries Management 16:840-850.

Logsdon, D. E., B. J. Pittman, and G. C. Barnard. 2004. Oxytetracycline marking of newly hatched walleye fry. North American Journal of Fisheries Management 24:1071-1077.

Logsdon, D. E. 2006. Contribution of fry stocking to the recovery of the walleye population in the Red Lakes. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report 535, St. Paul.

Logsdon, D. E. 2007. Use of unsectioned dorsal spines for estimating walleye ages. North American Journal of Fisheries Management 27:1112-1118.

Lucchesi, D. O. 2002. Evaluating the contribution of stocked walleye fry and fingerlings to South Dakota walleye populations through mass marking with oxytetracyline. North American Journal of Fisheries Management 22:985-994.

McWilliams, R. H., and J. G. Larscheid. 1992. Assessment of walleye fry and fingerling stocking in the Okoboji Lakes, Iowa. North American Journal of Fisheries Management 12:329-335.

Minnesota Department of Natural Resources. 1982. Lake management planning guide. Minnesota Department of Natural Resources, Fisheries Division Special Publication 132, St. Paul.

Minnesota Department of Natural Resources. 1996. Walleye stocking guidelines for Minnesota fisheries managers. Minnesota Department of Natural Resources, Section of Fisheries Special Publication 150, St. Paul.

Norris, D. 2007. Fish culture in wetlands: a review of the science and recommendations for licensing criteria. Minnesota Department of Natural Resources Section of Fisheries Special Publication 164, St. Paul.

Olson, M. H., T. E. Brooking, D. M. Green, A. J. VanDeValk, and L. G. Rudstam. 2000. Survival and growth of intensively reared large walleye fingerlings and extensively reared small fingerlings stocked concurrently in small lakes. North American Journal of Fisheries Management 20:337-348.

Parsons, B. G., and D. L. Pereira. 2001. Relationship between walleye stocking and year-class strength in three Minnesota lakes. North American Journal of Fisheries Management 21:801-808.

Parsons, B. G., and J. R. Reed. 2001. Methods to reduce stress and improve over-winter survival of stocked walleye fingerlings. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report 492, St. Paul.

Rasmussen, P. W., D. M. Heisey, S. J. Gilbert, R. M. King, and S. W. Hewett. 2002. Estimating post-spawning movement of walleyes among interconnected lakes of northern Wisconsin. Transactions of the American Fisheries Society 131:1020-1032.

Schupp, D. H. 1992. An ecological classification of Minnesota lakes with associated fish communities. Minnesota Department of Natural Resources, Section of Fisheries.