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ARTICLE

Fish Community Responses to the Introduction of Muskellunge into Minnesota Lakes

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Abstract
The popularity of sportfishing for muskellunge *Esox masquinongy* in Minnesota has increased substantially during the last 20 years and has resulted in a call for creating more fishing opportunities. As new waters are considered for muskellunge management, some anglers have expressed concern over the effects on other popular game fish species of adding a top-level predator. We evaluated the responses of seven fish species to muskellunge by comparing gill-net and/or trap-net catch per unit effort (CPUE) before and after muskellunge were stocked in 41 Minnesota lakes composed of 12 lake-classes. The species examined were northern pike *Esox lucius*, walleye *Sander vitreus*, yellow perch *Perca flavescens*, bluegill *Lepomis macrochirus*, black crappie *Pomoxis nigromaculatus*, white sucker *Catostomus commersonii*, and cisco *Coregonus artedi*. We found no significant decreases among the lakes in the mean CPUE of any species after muskellunge stocking, either for the stocked lakes as a whole or within lake-classes. There was a significant increase in the mean CPUE for bluegills over the entire group of lakes and within lake-class 24 in addition to an increase in the mean CPUE for black crappies sampled by gill nets in lake-class 25. Nevertheless, there was large variability in the changes in CPUE among lakes, and several individual lakes had significant changes in mean CPUE for some species following muskellunge stocking. The trend in CPUE increased for yellow perch and declined for white suckers over the entire group of lakes after muskellunge stocking. Because Minnesota follows established, biologically based guidelines for selecting new muskellunge lakes, the study lakes were not chosen at random and therefore the study conclusions most appropriately apply to lakes chosen in this manner. The lack of consistent negative changes in CPUE after stocking suggests that these fish species have generally coexisted well with muskellunge in these lakes at the densities that have resulted from stocking.

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Management of muskellunge *Esox masquinongy* in Minnesota has focused on developing high-quality trophy fisheries. The increase in angler reported catches of 50 in and longer muskellunge has been well documented in recent years (Younk and Pereira 2006; MUSKIES, Inc data). Schroeder et al. (2007) estimated that 14% of licensed anglers in Minnesota targeted muskellunge, and another 18% of non-muskellunge anglers were moderately or very interested in fishing for muskellunge in the future. The recent estimates of anglers fishing for muskellunge in Minnesota indicate substantial growth in muskellunge sportfishing compared with previous estimates (Wingate 1986; Schroeder and Fulton 2005). These characteristics lead many anglers and fisheries professionals to conclude Minnesota's muskellunge program has been successful. However, a successful program considers both biological and social aspects of a fishery. As new muskellunge waters were added or considered for potential management, some anglers expressed concern over the potential effects of introducing a top-level predator on other popular game fish species.

Species interactions are difficult to document in natural environments due to many uncontrollable and unknown variables. Research into the interaction of muskellunge with other species is further complicated by the fact that muskellunge populations naturally occur at low densities. Although sampling methods designed to target muskellunge have improved our understanding of muskellunge populations in the last 30 years, there remains a lack of information on the role of muskellunge within fish communities. Many studies have focused on the negative relationship between northern pike *Esox lucius* and muskellunge (Dombeck et al. 1986; Inskip and Magnuson 1986; Johnson 1981; Threinen and Oehmcke 1950; Oehmcke 1951); northern pike are considered to have an ecological advantage when the two species coexist, especially during early life stages (Hess and Heartwell 1978). Caplan (1982) observed predation on age-0 muskellunge by age-0 northern pike in an artificial environment, but the opposite did not occur. Predation, competition, and hybridization were discussed by Inskip (1986) as possible mechanisms of negative interaction between the two species. Studies investigating the interaction between largemouth bass *Micropterus salmoides* and muskellunge have generally focused on largemouth bass predation on stocked juvenile muskellunge or their hybrids and the ramifications for muskellunge culture and management (Stein et al. 1981; Carline et al. 1986; Szendrey and Wahl 1996; Wahl 1999). Miller and Menzel (1986) mentioned intraspecific and interspecific competition for prey, space, and other resources represented potential influences on muskellunge behavior. The authors noted that walleyes *Sander vitreus* appeared to be spatially segregated from muskellunge on West Okoboji Lake, Iowa, based on Pitlo (1978). Fayram et al. (2005) found a positive relationship between electrofishing catch rates for muskellunge and walleyes in 20 Wisconsin lakes, suggesting direct competition or predation was unlikely between these two species. In Minnesota, many of the best walleye fisheries are also native or stocked muskellunge fisheries. Despite the overlap of life histories for many predators, demonstrating that shared resources are limited at either the individual or population level, has been difficult.

A number of studies have documented the ineffectiveness of stocking muskellunge for improving the quality of panfish populations (Clark 1964; Oehmcke 1969; Snow 1988; Storck and Newman 1992). Stocking muskellunge fingerlings and imposing largemouth bass size limits failed to produce any significant improvement in fishing quality for bluegills *Lepomis macrochirus* at Loon Lake, Indiana (Pearson 2005). Presumably predation from low-density muskellunge populations could not compensate for the high reproductive potential of most prey species (Porter 1977).

Various studies have reported on the prey and selection of prey by muskellunge. Although there are documented cases of muskellunge consuming unusual items (e.g., frogs, salamanders, ducks, and muskrats), they are primarily piscivorous and generally do not select for a specific species (Parsons 1959; Porter 1977; Hess and Heartwell 1978). Laboratory studies have documented that esocids will select soft-rayed fishes over spiny-rayed species when abundance is nearly equal. The selectivity was more pronounced in hybrid muskellunge and northern pike than in muskellunge (Engstrom-Heg et al. 1986; Wahl and Stein 1988), although when soft-rayed and spiny-rayed species of the same size were present, muskellunge showed no significant selection between available prey species. Weithman and Anderson (1977) found nongame fish to be more vulnerable to yearling muskellunge predation than game fish.

Successful muskellunge populations are generally found in fish assemblages predominated by yellow perch *Perca flavescens*, catostomids, and species of *Coregonus*, whether in lakes or rivers. These species are important prey for muskellunge and other predator fishes. Throughout the muskellunge range, yellow perch have been documented as one of the most important prey items (Hourston 1952; Gammon and Hasler 1965; Inskip and Magnuson 1986; Bozek et al. 1999). Bozek et al. (1999) found yellow perch and white suckers *Catostomus commersonii* to be the primary food of muskellunge in a food habits study conducted in northern Wisconsin. Soft-rayed prey such as suckers, whitefish *Coregonus clupeaformis*, and ciscoes *Coregonus artedi* were found to be preferred prey in native Wisconsin muskellunge waters (Oehmcke et al. 1958). River and stream muskellunge were also found in association with soft-rayed species: white suckers, redhorse *Moxostoma* spp., and cyprinids (Harrison and Hadley 1979; Brewer 1980; Axon and Kornman 1986). Studies focused on the food habits of muskellunge are descriptive and important to fisheries management, but do not fully investigate the community interactions between muskellunge and other fishes.

The low-density nature of muskellunge populations, seasonal variation in sampling, and sampling across the various sizes of muskellunge provide challenges to all studies investigating muskellunge interactions with other fishes or food habits. Minnesota has 41 lakes with stocked populations of Mississippi

(MS) strain muskellunge that are considered quality fisheries with the potential for 50 in fish and standardized fisheries assessments (MDNR 1993) are conducted regularly on these lakes. The objective of our study was to evaluate whether muskellunge were having any measurable effects on the fish communities where they were introduced. We compared catch per unit effort (CPUE) data from assessment netting for seven species before and immediately after the first muskellunge stocking event in the 41 lakes. We analyzed data at three levels: at the individual lake level, pooled over lake-classes (Schupp 1992), and for all stocked muskellunge lakes combined.

METHODS

Of the 105 lakes and 6 rivers identified by Younk and Pereira (2006) as having muskellunge in Minnesota, we focused this study on a subset of 41 lakes distributed throughout Minnesota that are managed by stocking MS strain muskellunge (Table 1). The MS strain was first used in 1982 and was chosen for its superior growth characteristics and spatiotemporal differences in spawning characteristics compared with northern pike (Strand 1986; Younk and Strand 1992). Other muskellunge waters in Minnesota are either stocked with hybrid muskellunge or are self-sustaining populations.

We investigated changes in catch rates for seven species commonly sampled using standard netting assessment methods (MDNR 1993). Northern pike, walleyes, yellow perch, white suckers, black crappies *Pomoxis nigromaculatus*, and ciscoes were sampled using standard experimental gill nets. The gill nets had five panels with mesh sizes of 0.75, 1.00, 1.25, 1.50 and 2.00-in bar measure. Each panel was 6 ft high × 50 ft long and sewn to the others in ascending mesh size. Bluegills and black crappies were sampled using trap nets with a 0.75-in bar measure mesh size, a 3-ft-high × 6-ft-wide frame, and a 40-ft lead. We used CPUE (number of fish/overnight net set) as a measure of relative abundance for each species. Individual lakes were typically sampled at the same time each year using the same net locations during each assessment. These population assessments generally occurred in June, July, or August. No ice-out or spring trap-net data were included. No attempts were made to correct CPUE for seasonal trends in northern pike and walleye CPUE, as described by Grant et al. (2004).

The date of stocking was denoted as the point at which muskellunge were introduced and regularly stocked as fall fingerlings, or larger, into a particular lake. Before 1982, non-MS strains may have been stocked, and those waters were still considered stocked for the purpose of this analysis. Prestocking years included assessments occurring during the first year of stocking because muskellunge were stocked in the fall. We considered fry stocked years before fingerlings or larger fish were stocked as prestocked because most muskellunge fry stocking during the early years of the management program was unsuccessful in establishing fisheries. Hanson et al. (1986) also found muskellunge fry survival was generally low. Some lakes contained native populations of muskellunge in very low numbers or had muskellunge introduced in very low numbers before regular stocking began. In these cases, the effect of these few fish was assumed to be negligible, and assessments conducted before regular stocking were also considered to be prestocking.

Changes in catch data after stocking were analyzed at three levels: individual lake, pooled by lake-class, and all MS-stocked lakes pooled together. For analyses within an individual lake, we used a two-sample Wilcoxon rank-sum test (Venables and Ripley 2002) to compare CPUE for each species before and after muskellunge were introduced. This nonparametric procedure tests for a difference in median CPUE between the two periods, and because it is based on a ranking of CPUE observations, it is robust to data with large outliers. Results were considered significant at $\alpha = 0.05$. Fisheries CPUE data may be quite variable because of environmental changes, species-specific year-class fluctuations, and variation in sampling methods. Many lakes also had few observations; consequently, tests within a single lake typically had low power to detect changes in CPUE. By pooling lakes together, we improved our ability to detect whether muskellunge stocking had consistent effects across groups of lakes (e.g., mean CPUE tended to increase or decrease after stocking). Lakes were grouped according to Schupp's (1992) ecological classification system, which identifies subsets of Minnesota lakes that are similar in physical and chemical characteristics, such as total area, littoral area, maximum depth, shoreline development index, Secchi disk transparency, and Carlson's trophic state index. Four lake-classes (22, 24, 25, and 27) represented 32 of the 41 lakes (Table 2). Additional details on CPUE quartiles specific to study lakes and individual lake data may be found in Knapp et al. (2008).

For the group-level analyses, we used paired Wilcoxon rank-sum tests to examine the changes in both mean CPUE and CPUE trends after stocking. The difference in mean CPUE following muskellunge stocking (D_{CPUE}) was calculated for each lake in the group: D_{CPUE} = mean poststocking CPUE − mean prestocking CPUE. We then used a Wilcoxon rank-sum test to determine whether the typical D_{CPUE} value for a group of lakes was different from zero. If $D_{\text{CPUE}} < 0$, then CPUE following muskellunge stocking was generally lower for that group; if $D_{\text{CPUE}} > 0$, CPUE was generally higher. Changes in the mean weights (lb) of northern pike and walleyes following muskellunge stocking (D_{Wt} = mean poststocking weight – mean prestocking weight) were also included in both within-lake and pooled analyses because they represent the two species anglers are most often concerned about in regards to muskellunge management. The same test was also performed over all stocked lakes using the estimated trend in CPUE in place of mean CPUE. For each of the periods within each lake, the trend in CPUE was estimated by the slope of the regression line of $\log_e$(CPUE) versus the sample year; the difference between trends, D_{Trend}, was calculated by subtracting the prestocking trend estimate from the poststocking trend estimate, and as above, a Wilcoxon rank-sum test was used to determine whether the typical difference

TABLE 1. Selected characteristics of MS-stocked muskellunge lakes in Minnesota, including the number of assessments of fish populations before and after the stocking of muskellunge. The year stocked is the year of the first substantial and successful stocking of muskellunge. Lake-class refers to Schupp's (1992) ecological classification of Minnesota lakes.

				Number of assessments		
Lake	Lake-class	Area (acres)	Maximum depth (ft)	Pre	Post	Year stocked
Alexander	22	2,763	64	5	5	1988
Bald Eagle	24	1,269	36	4	4	1982
Beers	25	195	61	2	3	1977
Bemidji	22	6,420	76	3	7	1978
Big	27	3,533	35	2	7	1969
Big Mantrap	25	1,556	68	0	7	1957
Cedar	25	1,769	105	5	2	1994
Cross	25	943	30	4	7	1977
Detroit	22	3,083	89	6	4	1989
Dumbbell	5	437	40	5	10	1971
Eagle	24	291	34	3	6	1982
East Rush	24	1,359	24	1	8	1968
Elk	23	271	93	1	4	1982
Forest	24	2,251	37	7	4	1989
Fox	24	1,041	20	16	7	1999
French	24	816	56	0	7	1974
Harriet	24	335	87	4	7	1974
Independence	24	844	58	2	8	1971
Island	32	510	42	6	5	1982
Island Reservoir	2	8,112	94	2	7	1972
Little Wolf	31	490	24	3	4	1982
Lobster	25	1,308	65	1	8	1968
Mille Lacs	26	132,516	42	11	21	1984
Miltona	22	5,838	105	3	8	1982
Minnetonka	22	14,004	113	3	12	1977
North Star	25	1,059	90	4	4	1989
Oscar	38	1,040	25	3	5	1985
Owasso	24	384	37	10	4	1982
Pelican	22	3,986	55	3	8	1978
Plantagenet	22	2,529	65	3	4	1982
Pleasant	24	585	58	1	6	1978
Round	29	121	20	3	1	1990
Shamineau	27	1,626	52	4	5	1988
St. Croix	22	8,209	78	0	3	1989
Sugar	24	1,015	69	1	5	1970
Vermillion	2	40,557	76	10	22	1984
Waconia	27	2,996	37	5	6	1984
West Battle	27	5,624	108	1	9	1963
West Rush	25	1,464	42	1	8	1968
White Bear	22	2,416	83	3	6	1975
Zumbro	25	606	43	6	2	1994

in CPUE trend between the two periods was different from zero for the group of lakes. In some cases, data before or after the initial muskellunge stocking were insufficient to conduct statistical comparisons.

Ideally, before–after comparisons for the effects of stocking would include reference lakes that are similar in characteristics yet were not stocked so that the nature of any changes in the fishery observed after stocking could be judged relative to

TABLE 2. Mean values of selected physical and chemical variables for the 12 lake-classes (see Table 1) represented in this study. Abbreviations are as follows: SDF = shoreline development factor, TSI = trophic state index.

Lake-class	Area (acres)	Maximum depth (ft)	Littoral area (%)	Total alkalinity (ppm)	Secchi depth (ft)	SDF	Carlson's TSI	Number of lakes of that class
2	38,885	123.2	29.4	23.5	7.6	7.8	47.8	2
5	294	68.3	24.6	27.6	13.3	1.9	39.8	1
22	3,011	104.3	33.8	136.3	10.9	2.7	42.7	9
23	285	77.6	28.3	121.8	14.2	1.6	38.9	1
24	364	60.5	40.4	142.9	6.4	1.5	50.4	11
25	474	57.2	46.6	142.5	11.8	2.5	41.5	8
26	108,722	70.7	43.6	129.6	5.7	1.9	52.0	1
27	2,230	60.9	44.5	162.0	8.5	1.5	46.3	4
29	215	33.5	63.9	90.0	10.0	1.5	44.0	1
31	344	39.7	42.6	162.5	9.1	1.4	45.4	1
32	647	34.9	63.3	145.9	4.3	2.3	56.0	1
38	276	27.5	86.3	154.5	5.3	1.4	53.0	1

changes observed in the reference lakes. However, the stocked lakes were specifically chosen based on their suitableness to support a muskellunge population, and thus, it was difficult to find comparable reference lakes. Additionally, muskellunge were introduced into the lakes over several decades, so it would have been difficult to determine which nonstocked reference-lake years should have been compared with the stocked lakes after muskellunge had been introduced. As a form of control, mean CPUE was compared with lake-class CPUE quartiles to determine whether the relative abundance of fish species had differed since the introduction of muskellunge. Catches within the interquartile range (second and third quartiles) are generally viewed as normal for that lake class (Schupp 1992). Comparisons of the proportion of muskellunge-stocked lakes within the interquartile range before and after muskellunge stocking should demonstrate whether the abundance of a given species in stocked lakes changed relative to the nonstocked lakes.

RESULTS

Analyses of the entire group of MS-stocked lakes resulted in relatively normal distributions of differences in mean CPUE for all species with occasional outliers (Figure 1). Distributions shifted in either direction away from 0 (i.e., no change in CPUE) might suggest a muskellunge effect. Although the D_{CPUE} for each species varied among the lakes, all species except walleyes and bluegills had a median D_{CPUE} within ± 1.0. The observed overall increase for walleye CPUE (median $D_{\mathrm{CPUE}} = 1.72$) was not significant, whereas the overall increase for bluegills (median $D_{\mathrm{CPUE}} = 8.65$) was significant (Table 3).

For northern pike, there were no significant changes in CPUE following muskellunge stocking within lake-classes or for all MS-stocked lakes combined (Table 3). Mean weight of northern pike significantly increased overall for MS-stocked lakes, and within lake-class 24. Mean northern pike CPUE declined significantly in three lakes, and one lake had a significant increase (Table 4). Poststocking CPUE was within the lake-class interquartile range for 58% of the lakes, and 33% of the lakes were below the interquartile range; this distribution is similar to years before the introduction of muskellunge, when 64% of the lakes were within the interquartile range and 28% were below.

Mean walleye CPUE and CPUE trend were not significantly different overall for the MS-stocked lakes or for pooled lake classes (Table 3). There was a significant increase in CPUE for eight lakes following muskellunge stocking and a decline in two lakes (Table 4). No significant difference was found in the mean weight of walleyes when pooled across all MS-stocked lakes, but mean weight declined in lake-class 22 (Table 3). There were no significant differences in mean weights in other lake-classes. Mean CPUE for walleyes after the introduction of muskellunge was within the interquartile range for 55% of the lakes and above the third quartile in 33% of the lakes. This compares favorably to the years before muskellunge stocking, when 40% were within the interquartile range and 34% were above the third quartile.

Mean CPUE of yellow perch increased significantly in three lakes (Table 4), and though there were no significant differences in mean CPUE for the pooled MS-stocked lakes or lake classes, the trend in CPUE increased significantly following muskellunge stocking (Table 3). Mean poststocking CPUE was within the interquartile range 51% of the time and above the third quartile in 37% of the cases compared with 51% and 35%, respectively, for prestocked years.

Following muskellunge stocking, mean bluegill trap-net CPUE increased significantly for the entire group of lakes and within lake-class 24; however there was no significant change in CPUE trends following stocking (Table 3). Two lakes had significant increases in mean bluegill CPUE following muskellunge introduction (Table 4). Mean poststocking CPUE

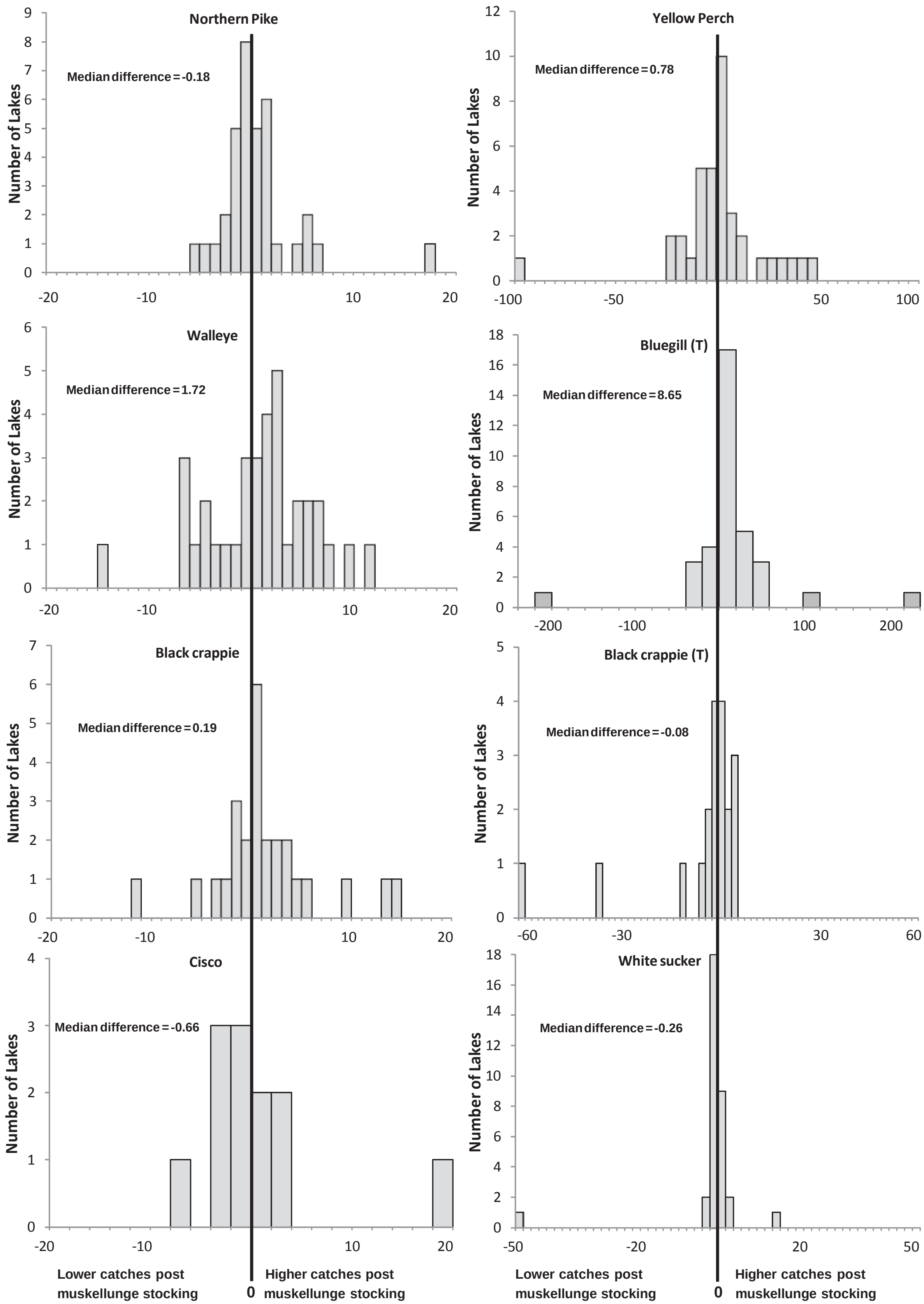

FIGURE 1. Distribution of the change in CPUE (Poststocking CPUE minus mean Prestocking CPUE) for individual lakes following muskellunge stocking for seven fish species. Differences of zero (one case each for northern pike and black crappies in trap nets) were excluded from this figure. The median difference (D) value for each species is reported in each graph. Bluegill and black crappies were sampled by trap nets (T). All other species were sampled with gill nets.

TABLE 3. Results of paired Wilcoxon rank-sum tests comparing mean catch per unit effort (CPUE [number of fish/overnight net set]), estimated values of the trend in CPUE, and mean weight (lb) before (pre) and after (post) the stocking of muskellunge in Minnesota lakes. Abbreviations are as follows: D_{CPUE} = the median difference in the observed values of CPUE, D_{trend} = the median difference in the estimated trend in CPUE, D_{Wt} = the median difference in weight, and n = the number of lakes. Results are shown for all study lakes and four specific lake-classes. Significant ($P \leq 0.05$) differences are denoted by bold italics.

Statistic	Northern pike	Walleye	Yellow perch	Bluegill	Black crappie (gill net)	Black crappie (trap net)	White sucker	Cisco	Statistic	Northern pike	Walleye
					All lakes						
CPUE pre	3.87	5.82	25.52	31.45	6.59	11.58	3.2	5.64	Weight pre	2.58	2.06
CPUE post	4.29	6.25	26.51	41.63	8.67	7.15	1.9	5.08	Weight post	2.88	2.04
D_{CPUE}	–0.18	1.72	0.78	8.65	0.19	–0.08	–0.26	–0.66	D_{Wt} Value	0.21	–0.15
n	36	35	37	34	26	20	33	12	n	29	28
P	0.76	0.29	0.53	***0.01***	0.2	0.63	0.32	0.5	P	***0.02***	0.11
D_{trend}	0.01	0	0.07	–0.01	0.02	0.02	–0.02	–0.02			
n	28	27	30	26	19	15	26	10			
P	0.37	0.70	***0.01***	0.63	0.71	0.89	***0.01***	0.23			
					Lake-class 22						
CPUE pre	6.59	7.52	25.75	30.37	2.67	17.12	2.45	5.01	Weight pre	2.21	1.92
CPUE post	5.22	8.55	26.34	35.82	1.59	1.63	2.56	2.83	Weight post	2.43	1.5
D_{CPUE}	–1.57	1.95	–0.34	5.38	–1.38	–0.59	–0.45	–1.3	D_{Wt} Value	0.22	–0.18
n	8	8	8	8	4	4	8	5	n	8	8
P	0.53	0.29	0.94	0.23	0.20	0.58	0.73	0.28	P	0.20	***0.05***
					Lake-class 24						
CPUE pre	2.85	3.99	32.21	20.96	11.55	16.24	1.09		Weight pre	3.17	2.04
CPUE post	4.42	4.9	28.45	64.39	16.74	11.77	0.64		Weight post	3.72	2.39
D_{CPUE}	0.83	2.51	2.61	23.45	3.19	–2.18	–0.65		D_{Wt} Value	1.03	0.04
n	10	8	10	10	10	9	8		n	8	6
P	0.22	0.62	0.76	***0.01***	0.13	0.29	0.29		P	***0.04***	1.00
					Lake-class 25						
CPUE pre	2.76	2.8	17.38	27.04	2.17	2.38	1.22	4.43	Weight pre	2.57	2.27
CPUE post	3.44	1.82	16.54	27.55	5.03	3.64	3.05	1.2	Weight post	2.77	2.24
D_{CPUE}	–0.35	–0.14	0.89	1.39	1.3	–0.18	0.2	–2.85	D_{Wt} Value	–0.37	–0.17
n	6	6	6	6	6	3	7	2	n	3	3
P	1.00	0.53	0.83	0.68	***0.04***	1.00	0.87	0.37	P	0.25	0.75
					Lake-class 27						
CPUE pre	4.16	7.76	28.42	21.74	6.95	1.81	2.35	2.55	Weight pre	2.28	1.97
CPUE post	6.97	6.36	20.21	40.34	5.57	4.38	1.18	3.84	Weight post	2.45	1.81
D_{CPUE}	3.22	–2.67	–9.95	19.4	0.18	2.57	–0.19	1.29	D_{Wt} Value	–0.03	0.05
n	4	4	4	3	3	2	3	2	n	4	4
P	0.20	0.58	0.36	0.18	1.00	0.37	0.18	0.37	P	1.00	1.00

was within the interquartile range for the lake-class 54% of the time compared with 59% before muskellunge were stocked. Mean CPUE was above the third quartile for the lake class 26% of the time after muskellunge were stocked compared with 15% before muskellunge were stocked.

Poststocking white sucker mean CPUE was not significantly different from prestocking years across all lakes or within lake-classes; however, the CPUE trend declined significantly following stocking (Table 3). Mean white sucker CPUE declined significantly in four lakes, whereas one lake had a

TABLE 4. Mean catch per unit effort (CPUE) for six fish species before (pre) and after (post) muskellunge stocking in Minnesota lakes. Pre–post differences with $P > 0.05$ were not considered significant and are not presented. The within-quartile comparison examines whether the mean CPUE after muskellunge stocking is below (N), above (Y+), or within (Y) the interquartile range for the lake-class. Individual lake data are from Knapp et al. (2008).

	Mean CPUE			Number of assessments		
Lake	Pre	Post	Two-tail *P*-value	Pre	Post	Within quartiles
			Northern pike			
Detroit	12.04	6.29	0.04	5	4	Y
Harriet	5.10	0.64	0.03	4	7	N
Mille Lacs	2.81	1.28	<0.01	11	21	Y
Minnetonka	5.94	11.83	0.04	3	12	Y+
			Walleye			
Cross	2.60	0.61	0.03	4	7	N
Dumbbell	3.78	14.97	0.05	3	10	Y+
Forest	2.03	4.99	0.01	7	4	Y
Fox	9.01	2.29	0.03	16	7	Y
Little Wolf	3.02	7.35	0.05	3	4	Y+
Minnetonka	1.56	4.47	0.03	3	12	Y
Oscar	3.42	8.46	0.04	3	5	Y+
Owasso	0.39	2.45	0.05	3	4	Y
Plantagenet	4.87	14.80	0.05	3	4	Y+
Waconia	1.11	7.20	0.04	5	6	Y
			Yellow perch			
Alexander	22.22	46.44	0.05	5	5	Y
Eagle	0.50	27.53	0.03	3	6	Y
Mille Lacs	14.38	61.05	<0.01	11	21	Y+
			Bluegill			
Eagle	20.00	48.95	0.04	3	5	Y
Pelican	5.30	52.72	0.02	3	8	Y+
			Black crappie (gill net)			
Fox	5.88	10.97	0.01	16	7	Y
			White sucker			
Bemidjii	3.07	6.45	0.04	3	7	Y+
Dumbbell	54.40	3.55	0.01	5	10	Y
Forest	0.18	0.02	0.02	7	4	N
Minnetonka	0.73	0.26	0.04	3	12	N
Shaminaeu	3.68	0.51	0.04	4	5	N

significant increase in CPUE (Table 4). Mean poststocking CPUE was within the interquartile range 53% of the time and below 36% of the time compared with 48% and 33%, respectively, during prestocking years.

Relative abundance of black crappies was measured using gill nets and trap nets. There were no significant changes in CPUE trend and mean CPUE was not significantly different for gill nets or trap nets for all lakes combined or for pooled lake classes, except for an increase in gill-net CPUE in lake-class 25 (Table 3). Mean black crappie CPUE was significantly higher in one lake sampled with gill nets, but no significant differences in trap-net CPUE were found in any lake (Table 4). Gill-net catches were within the interquartile range 45% of the time and exceeded the third quartile 48% of the time compared with 58% and 31%, respectively, before muskellunge stocking. Trap-net catches were within the interquartile range 59% of the time, exceeding the third quartile in 27% of the lakes, compared with 55% and 35%, respectively, for prestocked years.

Mean CPUE for ciscoes in the pooled sample of all MS-stocked lakes and lake-classes were not significantly different during poststocking years, nor were there any significant changes in CPUE trends following stocking (Table 3). Mean CPUE was not significantly different in any individual lake. Poststocking catches were within the interquartile range for 64% of the lakes and above in 21%. Before muskellunge introduction, 67% of the lakes were within the interquartile range and 33% were above.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Our results indicate that fish communities in lakes actively managed for muskellunge in Minnesota continue to do well and experienced similar variation in fish species abundance as other Minnesota lakes. Though white sucker abundance tended to decline following stocking, there were no consistent declines in mean CPUE for any popular Minnesota game fish species over the group of MS-stocked lakes, which suggests these fish species have generally coexisted well with introduced muskellunge populations. Further, comparisons with statewide lake-class quartiles showed that MS-stocked lakes generally maintained abundance levels similar to nonstocked lakes.

Though muskellunge stocking does not appear to have a pervasive effect on fish communities, there were 16 significant increases and 9 significant declines in mean CPUE for some species in the individual study lakes. Even so, these changes do not imply a benefit or harm to the fishery. Data were insufficient to determine whether muskellunge stocking caused these apparent abundance changes, or if the observed changes are spuriously correlated with the introduction of muskellunge. Many factors besides muskellunge have influenced fish communities and abundances in these lakes. Changes in fishing pressure, angler knowledge, and fishing technology along with changes to the lake environment, including habitat, productivity, and climate, have all played a role in shaping the fish communities that exist today. Fisheries management changes, such as northern pike stocking, various walleye stocking regimes, and regulation changes have also been important influences on fish communities.

Our results suggest the existing muskellunge management program has established muskellunge populations while generally maintaining the abundance and weight of sympatric northern pike populations. The potential effect of northern pike on muskellunge was beyond the scope of this study, though we note quality muskellunge populations in Minnesota have been maintained in the presence of various densities of northern pike. Considering the failures of earlier muskellunge fry stocking and that successful muskellunge populations have been maintained with fall fingerling stocking, current management that avoids interactions during the early life stages appears to be effective for minimizing negative interactions between the two species.

Our study found no significant difference in walleye CPUE following muskellunge stocking over the group of 41 lakes. Eight lakes showed significant increases in walleye CPUE after muskellunge were stocked, and only two lakes had significant decreases. Though we did not attempt to separate the effects of muskellunge from changes in walleye stocking strategies, our data illustrate walleye populations can be maintained or improved in the presence of muskellunge. Our study corroborates other work that also suggests that walleye and muskellunge management do not appear to be in conflict. Nate et al. (2003) attempted to predict the occurrence and success of walleye populations from physical and biological features of 120 northern Wisconsin lakes and found high largemouth bass and northern pike densities characterized lakes in which walleye populations were maintained by stocking, whereas lakes with self-sustaining walleye populations were associated with high walleye and muskellunge densities. Fayram et al. (2005) found a positive relationship between electrofishing catch rates for muskellunge and walleyes in 20 Wisconsin lakes, suggesting direct competition or predation was unlikely between these two species. Bozek et al. (1999) noted that despite large walleye populations in several study lakes (e.g., >20 fish/acre), walleyes did not appear to be an important food for muskellunge. While muskellunge and walleyes can be spatially segregated at times, they frequently observed walleyes and muskellunge in close proximity at night; yet when fresh prey in muskellunge stomachs were examined walleyes were rarely found. It appeared walleyes were either not preferred prey for muskellunge or walleyes were capable of avoiding predation.

Siler and Beyerle (1986) observed a decline in black crappie and white sucker abundance, whereas pumpkinseed *Lepomis gibbosus* and yellow perch numbers increased between two sampling events in 1967 and 1979. The authors suggested that this was related to the high-density muskellunge population of 2.2 mature fish/acre (in 1970). By comparison, estimated densities of adult muskellunge in Minnesota lakes are much lower at 0.07–0.39 fish/acre (MDNR 2008). Our study also had the benefit of prestocking data, a larger number of surveys on individual lakes, and multiple study lakes instead of a single case study. In a similar study across many Minnesota lakes, Grant et al. (2004) found a general statewide decrease in gill-net catch rates of black crappies sampled from 1982 to 1997. In contrast, we found no significant decreases in black crappie catch rates for MS-stocked lakes, and we found an increase in gill-net CPUE within lake-class 25. The lack of any corresponding decline in black crappie CPUE in MS-stocked lakes suggests the stocked muskellunge did not negatively impact black crappie populations.

White suckers, yellow perch, and ciscoes are three important prey species for muskellunge (Oehmcke et al. 1958; Bozek et al. 1999), and all these species have shown statewide declines in CPUE for the period 1989 through 2005 (MDNR, unpublished data). There were no significant differences in mean CPUE for white suckers, yellow perch, or ciscoes in our analyses; however, there were significant changes in the temporal trend in CPUE for white suckers and yellow perch following muskellunge stocking. For white suckers, CPUE trend declined following muskellunge stocking, and though this is similar to the declines observed in other Minnesota lakes, there is evidence that a sharper decline occurred in MS-stocked lakes during that period. However, yellow perch CPUE trend increased following muskellunge stocking, which is counter to the observed statewide declines. Although muskellunge stocking may have been associated with these temporal changes in CPUE, there was no general pattern of decline for the prey species in our study.

Although we did not test for changes in management strategies and species interactions, they could have substantial effects within individual lakes. For example, a management effort to remove white suckers and increase walleye stocking resulted in significant changes for both species on Dumbell Lake. Inverse changes were also observed between predator species such as walleyes and northern pike and prey species such as yellow perch and white suckers in four other lakes. These changes occurred over the same period as the muskellunge introduction, and demonstrate the possibility of factors other than muskellunge in shaping fish community structure.

We attempted to evaluate potential changes in catch rates before and after muskellunge introduction; we were unable to test for changes between initial and established muskellunge populations because partitioning data would have greatly reduced sample size, given the data available at this time. Continued sampling is underway in these lakes, and we recommend further study at some point in the future to evaluate potential short and long-term effects of muskellunge stocking. Our study was intended to evaluate past management with a simple before-and-after muskellunge introduction comparison in all of the stocked lakes; it was not to predict specific outcomes in other lakes. We also note that the lakes in this report represent a nonrandom group of waters chosen based on their relative potential for successful muskellunge introductions; therefore the conclusions should only be applied to other lakes using similar guidelines.

Muskellunge management within Minnesota has been scientific, systematic, and conservative (low to moderate density stockings) over the last 30 years in an effort to produce trophy fishing opportunities. The lake selection process for muskellunge stocking has typically focused on larger lakes with diverse fish communities because they offered the best potential for success. This stocking strategy appears to be successful in maintaining quality muskellunge fisheries across Minnesota without compromising other species coexisting in the same waters.

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