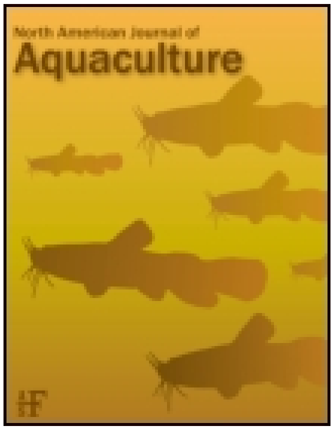
This article was downloaded by: [Troy G. Zorn]
On: 24 June 2015, At: 05:39
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Click for updates

North American Journal of Aquaculture
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/unaj20

Contribution of Hatchery-Reared Walleyes to Populations in Northern Green Bay, Lake Michigan

Troy G. Zorn[a]
[a] Michigan Department of Natural Resources, Fisheries Division, Marquette Fisheries Research Station, 484 Cherry Creek Road, Marquette, Michigan 49855, USA
Published online: 23 Jun 2015.

To cite this article: Troy G. Zorn (2015) Contribution of Hatchery-Reared Walleyes to Populations in Northern Green Bay, Lake Michigan, North American Journal of Aquaculture, 77:3, 409-422, DOI: 10.1080/15222055.2015.1044056

To link to this article: http://dx.doi.org/10.1080/15222055.2015.1044056

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

North American Journal of Aquaculture 77:409–422, 2015
© American Fisheries Society 2015
ISSN: 1522-2055 print / 1548-8454 online
DOI: 10.1080/15222055.2015.1044056

SPECIAL SECTION: HaMAR

Contribution of Hatchery-Reared Walleyes to Populations in Northern Green Bay, Lake Michigan

Troy G. Zorn*
Michigan Department of Natural Resources, Fisheries Division, Marquette Fisheries Research Station, 484 Cherry Creek Road, Marquette, Michigan 49855, USA

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

Abstract
The effectiveness of stocking hatchery-reared Walleyes *Sander vitreus* to supplement native populations in large, open systems like the Great Lakes has not been thoroughly evaluated. I quantified recent contributions of stocked Walleye fingerlings to populations in Little Bay de Noc (LBDN) and Big Bay de Noc (BBDN) in northern Green Bay, Lake Michigan. Oxytetracycline-marked Walleye fingerlings were stocked in June, and late summer gill-net and night-time boat electrofishing surveys were used to index Walleye year-class abundance and collect juvenile Walleyes for hatchery mark evaluation. For the 2004–2009 year-classes, 76% of the age-0 to age-3 Walleyes examined from LBDN were of wild origin and 62% in BBDN were naturally reproduced fish. Survey catch rates of juvenile Walleyes were similar for stocked and nonstocked year-classes. Assessment catch rates of age-1 and age-2 Walleyes differed significantly by location, with average catch rates in LBDN often being ten times higher than those in BBDN. Age-0 Walleyes persisted to older ages and were well-represented at numerous sampling locations in LBDN, but few age-1 and older Walleyes were caught in BBDN. The differences in growth between hatchery-reared and wild Walleyes were minor compared with the differences between bays. Based on stocking records and creel estimates available since 1985, the harvest rate of Walleyes was not significantly correlated to the numbers of Walleyes stocked 4–6 years earlier in LBDN or BBDN. Despite low stocking rates, stocked fish likely provided some contribution (though not a statistically significant one) to Walleye year-classes and the sport fishery in LBDN, but their contribution in BBDN was less apparent. Managers should weigh the trade-offs of supplemental stocking in Great Lakes waters when considering requests for hatchery Walleyes in smaller lakes and rivers, especially when stocking resources are limited.

Stocking hatchery-reared fish has been an important tool for restoring populations of native fish species, such as Walleye *Sander vitreus* in the Great Lakes of North America. For example, stocked Walleyes supplemented the spawning stock in Lake Huron's Saginaw Bay and supported a fishery for decades until ecological conditions became suitable for the population to become self-sustaining and able to maintain a suitable predator–prey balance (Fielder 2002; Fielder et al. 2007). In southern Green Bay, Lake Michigan, Walleye stocking in the Fox River was discontinued once natural reproduction was established (Kapuscinski et al. 2010). However, Walleye stocking continues in waters where natural reproduction remains low, such as the Muskegon River, a Lake Michigan tributary (O'Neal 1997).

Stocking to supplement naturally reproducing Walleye populations (i.e., supplemental stocking) may seem beneficial and is commonly done, but studies suggest it often has little effect and may be counterproductive (Kerr 2011). In comprehensive reviews of Walleye stocking in over 1,000 Minnesota lakes (Li et al. 1996a) and waters throughout North America (Laarman 1978), the authors concluded that supplemental stocking is the least successful type of stocking. Supplemental Walleye stocking was unambiguously successful (as evidenced by moderate to strong year-classes that included >50% stocked fish and stronger stocked than unstocked year-classes) in only 1 of 23 Wisconsin lakes studied by Jennings et al. (2005). The applicability of such findings to much larger, open systems like the

*E-mail: zornt@michigan.gov
Received February 20, 2014; accepted April 17, 2015

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

Great Lakes is limited because it is not feasible to stock Walleye fingerlings at densities similar to those used in previous stocking evaluations.

Native Walleye populations in Little Bay de Noc (LBDN) and Big Bay de Noc (BBDN) in northern Green Bay provided important commercial and sport fisheries until stocks collapsed in the 1960s. Rehabilitation efforts began shortly thereafter, with changes in regulations and a stocking program that used remnant LBDN spawners as a wild brood source. Though some natural reproduction was documented as early as 1988 (Schneider et al. 1991), supplemental stocking of Walleyes has continued, in part because quantitative information describing the extent of natural reproduction was lacking. Maybe more importantly, continued stocking may relate to the commonly held public opinion that population levels have not yet "recovered" and that supplementing the existing population with hatchery-reared Walleyes would enhance Walleye spawning stock size, recruitment, and the sport fishery. Development of rehabilitation targets for Walleyes specific to each bay is complicated by a lack of bay-specific historical harvest data, physical differences between the bays, and recent environmental changes, especially those associated with dreissenid mussels.

Quantifying the relative contributions of stocked and wild fish to populations provides a key metric for assessing Walleye rehabilitation. Thus, the overall objective of this study was to quantify recent contributions of supplementally stocked Walleyes to populations in LBDN and BBDN and provide this information to guide future Walleye management and stocking activities. The specific objectives for LBDN and BBDN were (1) to quantify the percent contributions of hatchery-reared Walleyes to individual year-classes; (2) to determine whether the catch rates of juvenile Walleyes in assessment netting and electrofishing surveys differed for stocked and nonstocked year-classes; (3) to compare the growth and relative survival of hatchery-reared and wild Walleyes from age 0 to age 3; and (4) to describe the spatial patterns in juvenile Walleye abundance and the percent contribution of hatchery Walleyes.

METHODS

Study areas.—The primary study areas, LBDN and BBDN, are located in the northern portion of Green Bay in northwestern Lake Michigan, and provide contrasting environments for Walleye populations. Little Bay de Noc is smaller, comprising 16,100 ha compared with 37,711 ha for BBDN. An abrupt contour break along much of LBDN's length produces fairly distinct shallow (<3-m) and deeper (12–30-m) habitats. Except for its southeastern shoreline, BBDN is generally shallow (over half of its area is <9 m deep) with gentle contours throughout. Little Bay de Noc is fed by the Whitefish, Rapid, Tacoosh, Days, Escanaba, and Ford rivers, which offer high-gradient rapids that provide suitable spawning habitat for Walleyes. The Whitefish River (catchment area, 794 km^2) likely supports the largest spawning run of Walleyes because it (1) is unfragmented in the lower half of its length; (2) has a natural flow and temperature regime; (3) has many kilometers of high-quality rapids for spawning; and (4) has extensive river mouth (nursery) habitat associated with its former role as a glacial outlet for Lake Superior. The larger Escanaba River (catchment area, 2,381 km^2) is affected by a dam located 3 km upstream of its mouth. In contrast, the major streams draining into BBDN (the Ogontz, Sturgeon, Big Fishdam, and Little Fishdam rivers) are all predominantly sandy in their lower reaches, providing limited spawning habitat for Walleyes. However, rocky reefs potentially suitable for Walleye spawning occur throughout BBDN (e.g., around St. Vital, Round, and Snake islands) and in portions of LBDN (e.g., near the mouth of the Whitefish River and along the western shore north of Gladstone). Additional sampling for this study occurred in the vicinity of the mouths of the Menominee and Cedar rivers, which drain into central Green Bay near the Michigan–Wisconsin border.

Fish stocking, assessment surveys, and creel survey.—Gametes were obtained from wild LBDN Walleyes at the mouth of the Whitefish River (typically in mid-April), fertilized on-site, and transported to the Michigan Department of Natural Resources (MDNR) Fisheries Division's Thompson State Fish Hatchery. Upon hatching, Walleye fry were marked with oxytetracycline (OTC) following the methods of Fielder (2002) and reared in outside ponds. The fish were harvested in late June or early July as "June fingerlings" (52 mm average length), and then stocked at several locations in Lake Michigan. June fingerling Walleyes were stocked into LBDN in 2004, 2006, and 2008, into BBDN in 2005 and 2009 (Table 1). Stocking rates ranged from 6 to 35 Walleyes per hectare in LBDN, and from 7 to 20 per hectare in BBDN. In June 2004, OTC-marked Walleye fingerlings were also stocked into Lake Michigan at the mouth of the Cedar River and at Stony Point, about 13 km north of the mouth of the Menominee River (Table 1). No Walleye stocking occurred in 2007 due to concerns about viral hemorrhagic septicemia virus (VHSV).

Gill nets and night-time boat electrofishing were used to index Walleye year-class strength and to collect juvenile Walleyes for OTC mark evaluation. More electrofishing effort occurred in LBDN due to concerns about nontarget mortality of adult Walleyes in gill nets, while most gill-netting effort occurred in BBDN, where bycatch of adult Walleyes in gill nets was less likely. Still, the use of comparable methods enabled catch rate comparisons between bays.

Gill-netting sites dispersed along the shoreline of each bay were established at the beginning of the study (15 sites in LBDN, 19 in BBDN), and each year nets were fished at a randomly selected subset of areas (4 in LBDN, 12 in BBDN) (Figure 1). Three gill nets were set overnight at each location identified for sampling, and nets were generally set in 2.4–4.6 m of water because preliminary sampling indicated consistent use of this depth range by juvenile Walleyes. Each gill net consisted of three 61-m × 1.8-m panels of 25, 38, and 51 mm stretch monofilament mesh.

Similar to the gill netting design, I established boat electrofishing areas (Figure 1) along the shoreline of each bay (9 in

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

TABLE 1. Number of Walleyes stocked by year, percent from natural reproduction, and number examined (n_x) by age- and year-class from sampling sites at LBDN, BBDN, and Lake Michigan near the Cedar and Menominee rivers. No aging structures were collected in 2003 in LBDN or BBDN since stocked Walleyes were unmarked and field techniques were being developed. For the Cedar and Menominee rivers, NS indicates that no sampling occurred in these years.

		Percent from natural reproduction and sample size								Year-class total	
Location and year-class	Walleyes stocked	Age-0 (%)	n_0	Age-1 (%)	n_1	Age-2 (%)	n_2	Age-3 (%)	n_3	All ages (%)	n_A
LBDN											
2003	0			100	81	100	2	95	19	99	102
2004	569,225	27	63	29	100	48	92	77	35	40	290
2005	0	97	157	96	120	94	80	96	26	96	383
2006	160,749	14	119	35	170	49	45	41	37	30	371
2007	0	100	234	100	413	93	101	94	77	98	825
2008	93,604	72	43	60	68	81	43	94	35	74	189
2009	0	90	63	87	15	94	33	72	25	88	136
BBDN											
2003	607,231			100	2	0	0	0	0		2
2004	0	86	7	50	2	0	1	0	0	70	10
2005	749,427	29	306	80	10	0	0	100	2	31	318
2006	0	100	46	100	13	100	4	100	1	100	64
2007	0	100	151	100	42	88	8	93	14	99	215
2008	0	100	14	75	4	67	3	0	0	90	21
2009	268,102	44	88	82	28	80	15	0	4	55	135
Cedar River											
2004	105,542	36	44							36	44
2005	0		NS			100	1			100	1
2006	0		NS	100	2					100	2
2007	0	100	21	100	4					100	25
2008	0	100	3							100	3
Menominee River											
2004	22,391		NS								0
2005	0		NS	100	4	100	3	100	8	100	15
2006	0	100	4	100	48	100	16			100	68
2007	0	100	33	100	28	100	7			100	68
2008	0		0								0

LBDN, 10 in BBDN), and randomly selected a subset of them for sampling each year (8 in LBDN, 4 in BBDN). Sampling a chosen area involved electrofishing at night along the shoreline in waters generally less than 3 m deep until at least 40 Walleyes less than 250 mm were collected or the amount of sampling time available in an 8-h work shift was exhausted. An average of 2.3 h (SD, 0.8 h) of electrofishing time occurred per night in each area selected for sampling. Electrofishing also occurred for one or two nights in Lake Michigan near the mouth of the Cedar River in 2004, 2007, and 2008 and near the mouth of the Menominee River in 2006, 2007, and 2008.

Electrofishing surveys occurred from 2003 to 2009 (2008 in BBDN), and gill-netting surveys occurred between 2003 and 2009. Electrofishing and gill-netting effort specifically targeting juvenile Walleyes in LBDN and BBDN declined in 2009 and 2010 with the implementation of a long-term fish community assessment gill-net survey in 2009. The fish community survey provided similar spatial coverage as the juvenile Walleye survey, and provided additional age-0 to age-3 Walleyes from the 2004–2009 year-classes for OTC mark evaluation. However, the change in assessment gear prevented computation of gill-net catch indices for age-1 to age-3 Walleyes from the 2009 year-class.

Individual lengths and weights were recorded for Walleyes, and the first three dorsal spines were removed for age determination. Walleyes less than 400 mm were individually bagged and frozen for OTC-mark evaluation. Detection of OTC marks in otoliths followed the methods of Fielder (2002) and was performed by personnel at the MDNR Fisheries Division's Alpena Fisheries Research Station. Fish were scored as either marked

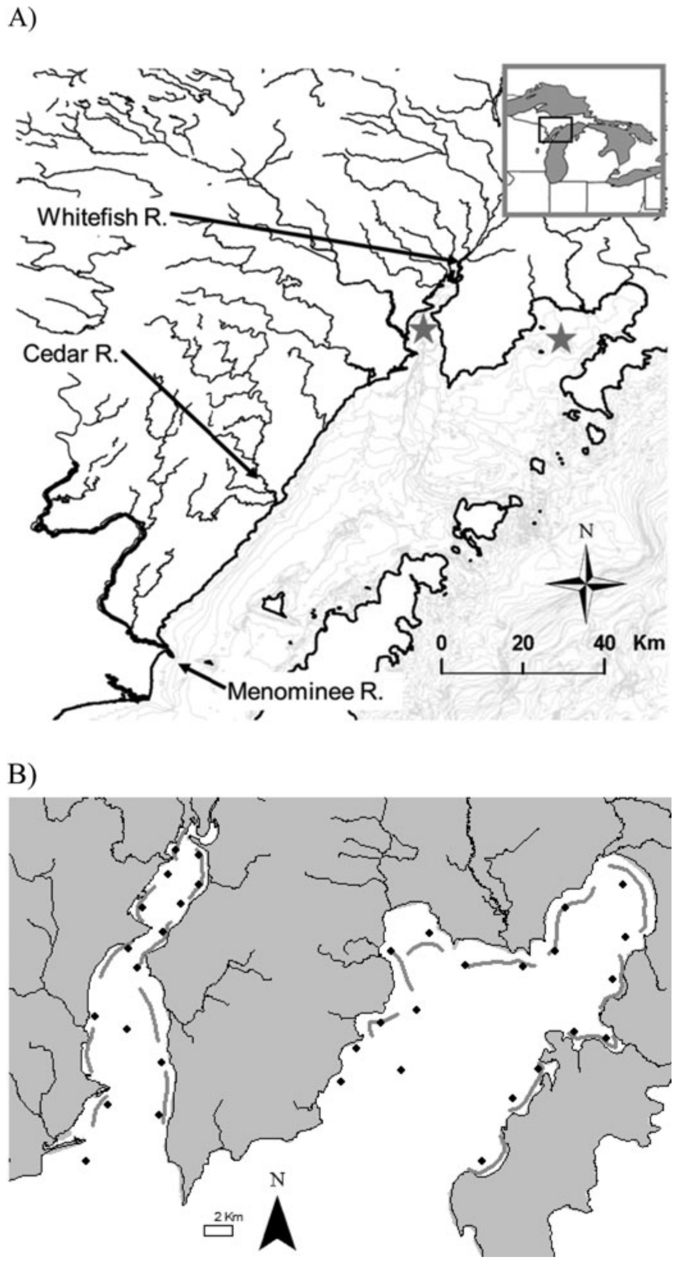


FIGURE 1. Maps showing **(A)** the Green Bay assessment areas of Little and Big Bay de Noc (western and eastern gray stars) and the Menominee and Cedar rivers and **(B)** the potential sampling locations for gill-net (diamonds) and electrofishing (gray lines) surveys in Little Bay de Noc and Big Bay de Noc.

(i.e., hatchery fish) or unmarked (i.e., wild fish). Examination of the annual samples of OTC-marked Walleyes obtained from hatchery ponds confirmed that OTC marks were successfully applied and 100% detectable each year.

To complement the above data and provide longer-term insight into the influence of stocked Walleyes on the sport fishery, I obtained Walleye harvest and nontargeted angler effort data for the Michigan waters of Green Bay from an on-site creel survey conducted annually by Michigan Department of Natural Resources personnel since 1985 (Federal Aid to Sport Fish Restoration, Grant F-81-R, Study 499). The creel survey was conducted during both the ice and open-water fishing periods on LBDN but only occurred during the open-water season on BBDN and Lake Michigan near the ports of Menominee and Cedar River.

Statistical analyses.—I used analysis of variance (ANOVA) to determine whether assessment-based catch rates (electrofishing catch per hour or gill-net catch per net night) of age-0, age-1, and age-2 Walleyes varied as a function of location (LBDN or BBDN), whether or not stocking had occurred, and the numbers of fish stocked. Location and the occurrence of stocking were categorical fixed effects in the model, and the number of Walleyes stocked was a covariate. The same model structure was used to assess the influence of these variables on the estimated percent contribution of naturally reproduced Walleyes for ages 0–3 for each bay and year. The data were transformed as necessary to meet the distributional assumptions of ANOVA. All statistical analyses were done using SPSS version 19.0, with the rejection criterion $\alpha = 0.05$ for all analyses.

I used ANOVA to assess whether the variation in length at age of age-0 to age-3 Walleyes could be explained by origin (hatchery versus wild), location, or year. In this analysis, origin was a fixed effect, while location and year were treated as categorical covariates. Marginal (least-squares) mean lengths at age of LBDN and BBDN Walleyes were computed to account for unequal sample sizes across blocks.

I used analysis of covariance (ANCOVA) in a general linear model to compare the relative condition of hatchery and wild Walleyes in the two bays. In this model, $\log_{10}$ transformed total weight (g) was the response variable and $\log_{10}$ transformed total length (mm) and origin (hatchery or wild) were fixed effects. A significant length $\times$ origin interaction term was indicative of a significant influence of origin on the length–weight relationship.

I used ANOVA to assess whether the percent contribution of wild Walleyes to year-classes remained consistent over time in LBDN as year-classes aged. This analysis was done only for LBDN, where relatively large samples of age-0 and older Walleyes were available. The percent wild for the Walleye year-class was the dependent variable, Walleye age and whether or not the year-class was stocked were fixed effects, and year-class was a categorical covariate.

I assessed the potential influence of stocked Walleyes on the sport fishery in LBDN, BBDN, and Lake Michigan near the Menominee and Cedar rivers, by examining Pearson correlations between annual values of estimated Walleye harvest per hour by anglers and numbers of Walleyes stocked 4–6 years earlier at each location. The 4-year lower cutoff was used because most Walleyes in the Michigan waters of Green Bay are not of a legally harvestable size (381 mm) for an entire open-water fishing season until age 4. The 6-year upper cutoff was chosen because the influence of strong Walleye year-classes (or those strengthened by hatchery-reared fish) is most noticeable in the fishery during the initial years after fish have

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

reached legal size for harvest, and after 6 years Walleyes would have been available to angler harvest for three full years. Examination of longer time periods yielded similar findings (author's unpublished data), but they would have been more difficult to interpret due to the combination of a larger number of year-classes. While these long-term data were informative, the strength of the correlation analysis was limited by the nonindependence of the stocking variable, since the age composition of harvested Walleyes was unavailable and it was likely that multiple stocked and wild year-classes contributed to the annual harvest.

RESULTS

Between 2004 and 2009, 823,578 OTC-marked fingerling Walleyes were stocked into LBDN and over 1,017,529 were put into BBDN. Seventy-six percent (1,668) of the 2,194 age-0 to age-3 Walleyes examined from the 2004–2009 year-classes in LBDN were of wild origin, while 475 (62%) of the 763 Walleyes in BBDN were wild fish (Table 1). Based on the results for age-0 to age-3 Walleyes, the percent contribution of natural reproduction to stocked year-classes was 40% (2004), 30% (2006), and 74% (2008) in LBDN and 31% (2005) and 55% (2009) in BBDN.

Walleye reproductive success varied by year and location. The overall assessment gear catch in LBDN was highest for the nonstocked 2007 year-class, and this year-class represented the second highest catch in BBDN (Table 1). Well over 10 Walleyes were collected for each year-class (2004–2009) and age-group (age-0 to age-3) combination in LBDN, but in BBDN fewer than 10 Walleyes were obtained for many year-class and age-group combinations (Table 1). Some nonstocked years in BBDN were represented by very few Walleyes (e.g., 10 Walleyes for the 2004 year-class). The total catches of juvenile Walleye year-classes in gill-net and electrofishing assessment gear were consistently higher in LBDN than BBDN, with the numbers of age-1 to age-3 Walleyes collected in a given year in LBDN often being ten or more times higher than those in BBDN (Table 1).

Stocking of hatchery fish had little effect on the catch rates of juvenile Walleyes in the assessment gear. The gill-net and electrofishing catch rates of age-0, age-1, and age-2 Walleyes did not differ significantly between stocked and nonstocked years, except for the age-2 gill-net catch rate of Walleyes, which on average was higher for nonstocked years in both bays (Table 2; Figure 2). In LBDN, the average catch rates for nonstocked year-classes of Walleyes at ages 0, 1, and 2 from the gill-net and electrofishing surveys were higher than those for stocked years, though the differences were often not statistically significant (Figure 2; Table 3). The lack of significant bay $\times$ stocking interactions in each ANOVA indicates that stocking effects were consistent between bays (Table 2). The number of Walleyes stocked did not have a significant effect on age-0, age-1, or age-2 gill-net or electrofishing assessment catch rates, with one exception: the age-2 gill-net catch rate (Table 2). Neither the number of Walleyes stocked ($P = 0.31$) nor the occurrence of stocking ($P = 0.06$) had a significant effect on the percent contribution of wild Walleyes to year-classes, based on the combined results from the OTC evaluations for age-0 to age-3 fish (Tables 1, 2).

The assessment catch rates of age-1 and age-2 Walleyes differed significantly by location, with those in LBDN often being ten times higher than those in BBDN (Tables 2, 3; Figure 2). For example, the average electrofishing catch rates for unstocked year-classes of Walleyes at age 1 were 20 times greater in LBDN than BBDN (6.4 versus 0.3 Walleyes per hour), and the gill-net catch rates were comparably different (9.0 versus 0.5 Walleyes per net night). The catch rates of age-0 Walleyes in electrofishing surveys differed significantly between bays, but the gill-net catch rates of age-0 Walleyes did not (Tables 2, 3). For example, the average electrofishing catch rates of age-0 Walleyes for unstocked year-classes were 19 times greater in LBDN than BBDN (13.5 versus 0.7 Walleyes per hour), while the average gill-net catch rates were only twice as high (4.1 versus 1.5 Walleyes per net night).

The spatial patterns in juvenile Walleye catch were similar for both gear types, showing differences between bays. Moderate catches of age-0 Walleyes in gill nets were spread throughout LBDN, and BBDN showed higher catches along its northern and western shorelines (Figure 3). Age-0 Walleyes persisted to older ages and were well-represented at numerous sampling locations in LBDN, but the fate of age-0 Walleyes in BBDN was less clear since few age-1 and older Walleyes were caught. Electrofishing catch rates of age-0 Walleyes were strong and dispersed throughout LBDN but were lower and more spatially restricted in BBDN (Figure 4). Few age-1 and no age-2 or age-3 Walleyes were collected from electrofishing areas in BBDN. In contrast, Walleyes in these age-groups remained relatively abundant and widely distributed in LBDN.

Some areas had higher overall catch rates of age-0 to age-3 Walleyes and disproportionally higher representation of Walleyes of wild origin (Figure 5). Such locations in LBDN included areas south of the mouth of the Escanaba River (the southernmost stocking site), particularly along the western side of the bay, and the northern portion of the bay between the town of Gladstone (near the two central stocking sites) and the Days River (along the west shore south of the northernmost stocking location). Higher catches and representation of Walleyes of wild origin in BBDN occurred in the northeastern portion of the bay. The capture of stocked Walleyes up to 8 km from the nearest stocking location indicates considerable movement from stocking locations in both bays (Figure 5).

The differences in growth between hatchery-reared and wild Walleyes were minor compared with the differences in Walleye growth between bays. Walleyes of wild origin were significantly longer at age 0 (177 mm versus 161 mm), but no significant differences in length occurred at ages 1, 2, or 3

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

TABLE 2. P-values from ANOVA modeling of the effects of bay (Little Bay de Noc or Big Bay de Noc), stocking (stocking or not stocked), and number of Walleye fingerlings stocked on catch rates of age-0 to age-2 Walleyes in gill-net and electrofishing assessment surveys and the overall percentage of each year-class that was from natural reproduction (based on age-0 to age-3 Walleyes); N = the total number of samples used in the analysis.

Age-class	Source of variation	F	P	df
	Gill-net CPE			
Age 0 ($N = 14$)	Number stocked	0.14	0.716	1, 9
	Bay	0.58	0.466	1, 9
	Stocking	1.30	0.283	1, 9
	Bay × stocking	4.59	0.061	1, 9
Age 1 ($N = 12$)	Number stocked	0.00	0.959	1, 7
	Bay	10.83	0.013	1, 7
	Stocking	0.06	0.812	1, 7
	Bay × stocking	0.42	0.536	1, 7
Age 2 ($N = 10$)	Number stocked	10.85	0.022	1, 5
	Bay	148.77	<0.001	1, 5
	Stocking	11.40	0.020	1, 5
	Bay × stocking	3.63	0.115	1, 5
	Electrofishing CPE			
Age 0 ($N = 13$)	Number stocked	1.29	0.289	1, 8
	Bay	7.13	0.028	1, 8
	Stocking	0.67	0.438	1, 8
	Bay × stocking	2.74	0.137	1, 8
Age 1 ($N = 11$)	Number stocked	0.91	0.376	1, 6
	Bay	9.81	0.020	1, 6
	Stocking	0.28	0.613	1, 6
	Bay × stocking	0.36	0.569	1, 6
Age 2 ($N = 9$)	Number stocked	0.00	0.962	1, 4
	Bay	23.00	0.009	1, 4
	Stocking	0.16	0.707	1, 4
	Bay × stocking	0.55	0.500	1, 4
	Percent wild			
Age 0 to age 3 ($N = 13$)	Number stocked	1.18	0.310	1, 8
	Bay	0.00	0.986	1, 8
	Stocking	4.76	0.061	1, 8
	Bay × stocking	0.14	0.718	1, 8

(Table 4). For each age, BBDN Walleyes had higher mean lengths at age than LBDN Walleyes, with the bay variable being significant in each ANOVA model (Table 4; Figure 6). The lack of a significant origin × length interaction in ANCOVA models relating the total lengths and weights of individual Walleyes in each bay indicates that Walleyes of hatchery and wild origin were of similar condition (Table 4).

In LBDN, I found that for stocked year classes the percent contribution from natural reproduction increased as year-classes aged (Table 1; Figure 7). The ANOVA model indicated that the percent contribution of wild Walleyes varied significantly with age-class and year-class (Table 4).

Correlations between estimated angler harvest rates from creel surveys and prior stocking provided a longer term view of the potential contributions of stocked Walleyes to the sport fishery, since data were available back to 1985 (Figure 8). The harvest rate of Walleyes was not significantly correlated to the numbers of Walleyes stocked 4–6 years earlier in LBDN ($r = 0.29$; $P = 0.13$), BBDN ($r = -0.02$; $P = 0.91$), or Lake Michigan near the Cedar River ($r = -0.01$; $P = 0.98$). However,

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

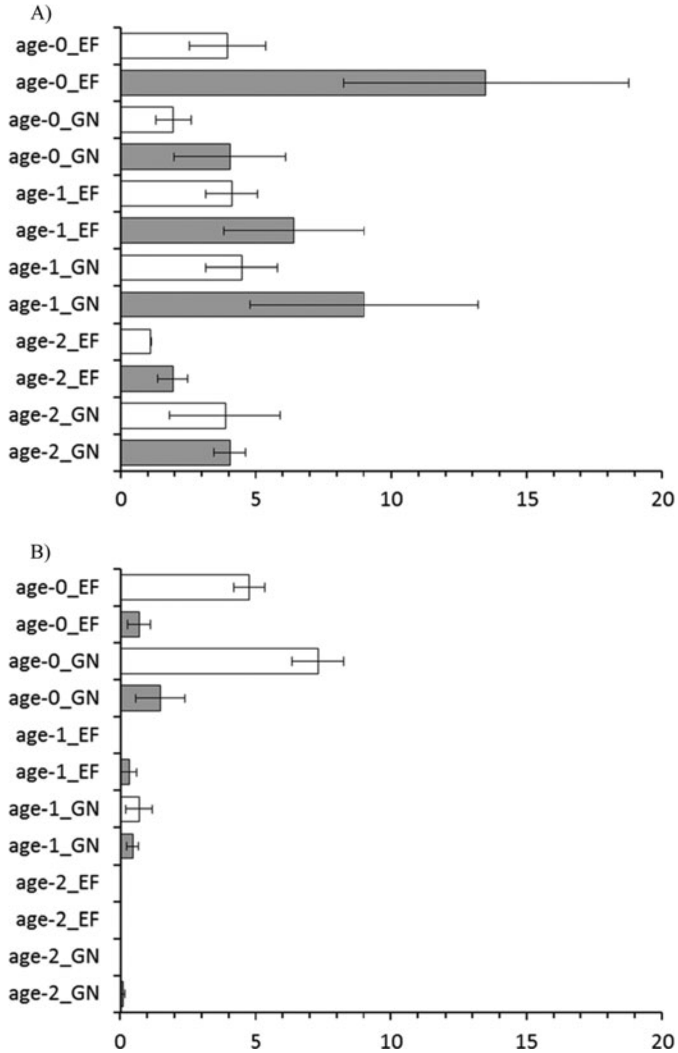


FIGURE 2. Mean gill-net (GN) and boat electrofishing (EF) survey catch rates for age-0 to age-2 Walleyes in **(A)** Little Bay de Noc and **(B)** Big Bay de Noc for stocked (white bars) and unstocked (gray bars) year-classes. The units on the *x*-axes are the numbers of Walleyes caught per hour of electrofishing or per 183-m gill net. The error bars represent SEs.

a significant positive association between Walleye harvest rate and stocking occurred at the Menominee River ($r = 0.64$; $P < 0.01$).

DISCUSSION

Previous studies suggest that supplemental stocking has little if any effect on Walleye abundance and can lead to decreased survival and growth (Kerr 2011). Supplemental stocking had no statistically significant effects on population abundance in Minnesota lakes where natural reproduction of Walleyes occurred (Li et al. 1996b). Li et al. (1996b) found that in Minnesota lakes in which stocking hatchery-reared Walleyes increased the abundance of a year-class, it also decreased the abundance of the Walleyes 1 year younger and 1 year older than the stocked year-class. In a review of supplemental stockings in Great Lakes states and provinces, Kampa and Jennings (1998) concluded that stocking Walleyes in water bodies in which natural reproduction occurs is usually not successful. Although some stocked fish survive, the suppression of adjacent year-classes led to no increases in population size (Kampa and Jennings 1998). Agency studies in Wisconsin and Ontario recommend against stocking Walleyes in waters where natural reproduction occurs (Kerr et al. 1996; Kampa and Jennings 1998). Several other states and provinces stock Walleyes every 2–3 years in waters where natural reproduction occurs (Kerr 2008, 2011). Laarman and Schneider (1986) concluded that returns of Walleyes stocked in a Michigan lake could be optimized by stocking every 2–3 years instead of annually. The Michigan Department of Natural Resources (MDNR) Fisheries Division's fish stocking guidelines recommend no Walleye stocking for 2–3 years if measured reproductive success is "relatively good" and stocking on a 2–3 year rotation if reproductive success cannot be evaluated annually (MDNR 2004). In their broad survey of Minnesota lakes, Li et al. (1996a) found that in places where total Walleye abundance increased from stocking the average weight of individual fish decreased.

Increased understanding of the effectiveness of and concerns with supplemental Walleye stocking appears to have led to a general change over time in the use of hatchery Walleyes by fishery managers. For example, a 1996 survey of Walleye stocking programs across North America by Fenton et al. (1996) reported that supplemental stocking was the highest priority. However, a more recent 2006 survey of Walleye stocking in North American states and provinces found that more agencies were using Walleyes to create and maintain artificial fisheries with little expectation of natural reproduction (Kerr 2008, 2011), implying a decline in supplemental stocking as a management priority.

The results of this study contrast somewhat with those of previous studies of supplemental Walleye stocking, and may be explained by the study location and the stocking rates. Little Bay de Noc and BBDN are very large bays connected to Lake Michigan, and it was not feasible to achieve the 124 spring fingerlings/ha stocking rate used in the Wisconsin study (Jennings et al. 2005) or MDNR's recommended rate of 62–247 fingerlings/ha (MDNR 2004). The stocking densities used here were less than a quarter of the stocking rate of the Jennings et al. (2005) study, in which negative effects were observed, and generally less than half of the rates used in a study of three Minnesota lakes (Parsons and Pereira 2001). I found that stocked fish contributed a measureable percentage to year-classes in both water bodies, but stocking densities were low enough that year-classes supplemented with stocked Walleyes were not significantly larger than year-classes that did not receive stocked fish. This concurs with a Minnesota study that found that stocking Walleyes into lakes where reproduction was already occurring had no effect on Walleye abundance (Li et al. 1996a). The lower stocking densities used in this study may have lessened the likelihood of negative effects of hatchery-reared Walleyes on

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

TABLE 3. Year-class-specific summaries for Little and Big Bay de Noc of the numbers of OTC-marked Walleye fingerlings stocked, the percent of the year-class from natural reproduction, the number of age-0 to age-3 Walleyes examined (n), electrofishing catch per hour (CPH) and annual survey effort, and gill-net catch per net night (CPE) and annual gill-netting effort. Average catch and effort are also shown for all stocked and nonstocked year-classes. Walleyes stocked into BBDN in 2003 were not marked.

				Electrofishing CPH and effort				Gill-net CPE and effort			
Year-class/type	Number stocked	Percent wild	n	Age 0	Age 1	Age 2	Effort (h)	Age 0	Age 1	Age 2	Effort (lifts)
Little Bay de Noc											
2003	0	99	102	26.91	7.68	1.13	13.64	0.50	2.50	3.25	2
2004	569,225	40	290	6.26	2.25	1.15	18.37	1.50	4.42	5.92	12
2005	0	96	383	3.87	1.41	1.74	22.21	5.92	7.58	3.67	12
2006	160,749	30	371	4.23	4.65	1.11	19.16	3.25	6.83	1.83	12
2007	0	98	825	16.76	10.16	2.98	18.91	9.00	16.92	5.20	12
2008	93,604	74	189	1.40	5.44		20.68	1.17	2.20		12
2009	0	88	136	6.48			7.72	0.80			10
Stocked				3.96	4.11	1.13	19.40	1.97	4.48	3.88	12
Not stocked				13.50	6.41	1.95	15.62	4.05	9.00	4.04	9
Big Bay de Noc											
2003	607,231		2	4.19	0.00	0.00	8.83	6.90	1.21	0.06	10
2004	0	70	10	0.00	0.11	0.00	7.14	0.33	0.06	0.00	24
2005	749,427	31	318	5.36	0.00	0.00	17.73	5.92	0.22	0.00	36
2006	0	100	64	0.51	0.00	0.00	9.74	1.14	0.36	0.11	36
2007	0	99	215	1.99	0.89		6.53	4.17	1.08	0.22	36
2008	0	90	21	0.33			8.99	0.31	0.33		36
2009	268,102	55	135					9.11			9
Stocked				4.77	0.00	0.00	13.28	7.31	0.72	0.03	18
Not stocked				0.71	0.33	0.00	8.10	1.49	0.46	0.11	33

adjacent nonstocked year-classes and limited the detectability of changes in year-class abundance. Comparable growth rates among stocked and wild fish suggest that stocked Walleyes (at least after reaching age 1) are as likely to survive and contribute to the sport fishery as their wild counterparts. The weak, but positive, association between the number of Walleyes stocked and angler harvest rates in LBDN also suggests that this is the case.

The degree to which stocked Walleyes contribute to the BBDN Walleye stocks and the fishery is less apparent. Stocked Walleyes were evident in assessment surveys at age 0 but declined notably by age 1 and were rarely encountered at ages 2 or 3. This was the case for both hatchery-reared and wild Walleyes (Table 3). The decline in catch may relate to the movement of age-1 and older Walleyes to deeper waters several km further offshore, beyond the reach of my assessment gear. In the extensive flats of BBDN, age-0 fish may also be more vulnerable to other nearshore predators, such as the abundant Smallmouth Bass *Micropterus dolomieu* population and a nesting colony of double-crested cormorants *Phalacrocorax auritus* (USFWS 2011; Zorn, unpublished data). In contrast, age-0 to age-4 Walleyes (both hatchery-reared and wild) were readily captured in LBDN, where much of the shoreline includes shallow flats immediately adjacent to waters over 10 m deep. Since it is more than twice as large as LBDN, BBDN was stocked at a lower rate, which might also contribute to the lower assessment catches. Unlike Lake Michigan at Menominee, there was no positive association between the number of fingerling Walleyes stocked and subsequent angler harvest rates in BBDN.

Since these Lake Michigan habitats are being stocked at low rates relative to inland lakes, it seems reasonable to ask whether these low-density stockings are contributing to the fishery. Even though I could not confirm the relative contributions of stocked versus wild Walleyes to angler creels, positive (though not statistically significant) associations between annual Walleye harvests and the number of Walleyes stocked 4–6 years earlier suggest a positive contribution to the sport fisheries in LBDN and even more so for that at Lake Michigan at the Menominee River. The lack of comparable relationships for BBDN and Lake Michigan at the Cedar River indicate that Walleye harvests there are more strongly tied to factors other than stocking. For example, most of the Walleyes that were marked with jaw tags in the Cedar River area during the spring spawning period were later recaptured in or around the Menominee River or further south in Green Bay (Zorn and Schneeberger 2011). Such movement patterns suggest that variation in the abundance of southern Green

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

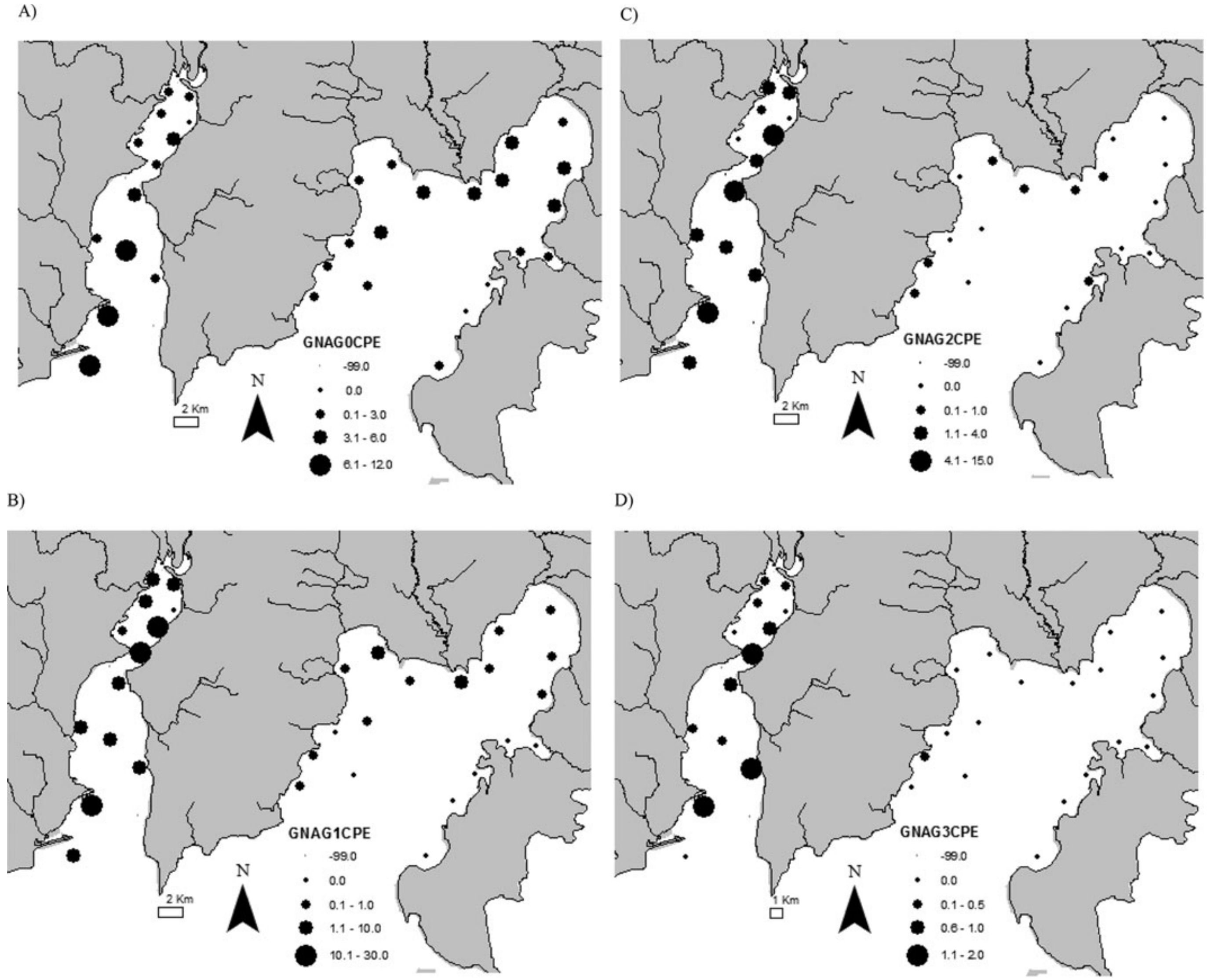


FIGURE 3. Mean catch per overnight gill-net set by location for **(A)** age-0, **(B)** age-1, **(C)** age-2, and **(D)** age-3 Walleyes during 2004–2009.

Bay Walleye stocks influences trends in the angler harvest of Walleyes in the Cedar River area.

The differences in the gill-net and electrofishing catch rates of juvenile Walleyes between LBDN and BBDN are generally consistent with the results of recent studies of Walleyes in those two bays. Higher catches of juvenile Walleyes in LBDN fit with data from on-site angler creel surveys, statistical catch-at-age model estimates, and fish community assessments. The annual angler harvest of Walleyes in BBDN and LBDN for 1985–2005 averaged 2,363 and 27,065 fish, respectively (Kapuscinski et al. 2010), and recent statistical catch-at-age model estimates of age-4 and older Walleyes show about a fivefold difference between the two bays (Zorn, unpublished data). However, recently discovered commercial harvest data from the State of Michigan archives for 1941–1957 (the period of peak commercial Walleye harvest) indicate a smaller difference, with average annual Walleye harvests of 88,200 and 72,600 kg for commercial fisherman based at ports in LBDN and BBDN, respectively. Collectively, these data suggest that present LBDN habitats have greater potential for Walleye reproduction than those in BBDN.

The higher Walleye abundance in LBDN today seems consistent with the differences in habitat conditions between the bays. For example, LBDN has numerous large to medium-sized undammed rivers with high-gradient rapids for spawning (i.e., the Whitefish, Rapid, Tacoosh, and Ford rivers); excellent sheltered reef-spawning and nursery habitats for developing eggs, fry, and juvenile Walleyes; and deepwater habitats adjacent to shallow flats for foraging. Recent surveys of Walleye spawning populations in LBDN tributaries, including the Ford, Escanaba, Whitefish, and Rapid rivers, showed strong runs, with estimates well into the thousands of Walleyes in each river (Zorn, unpublished data). Big Bay de Noc, on the other hand, has more

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

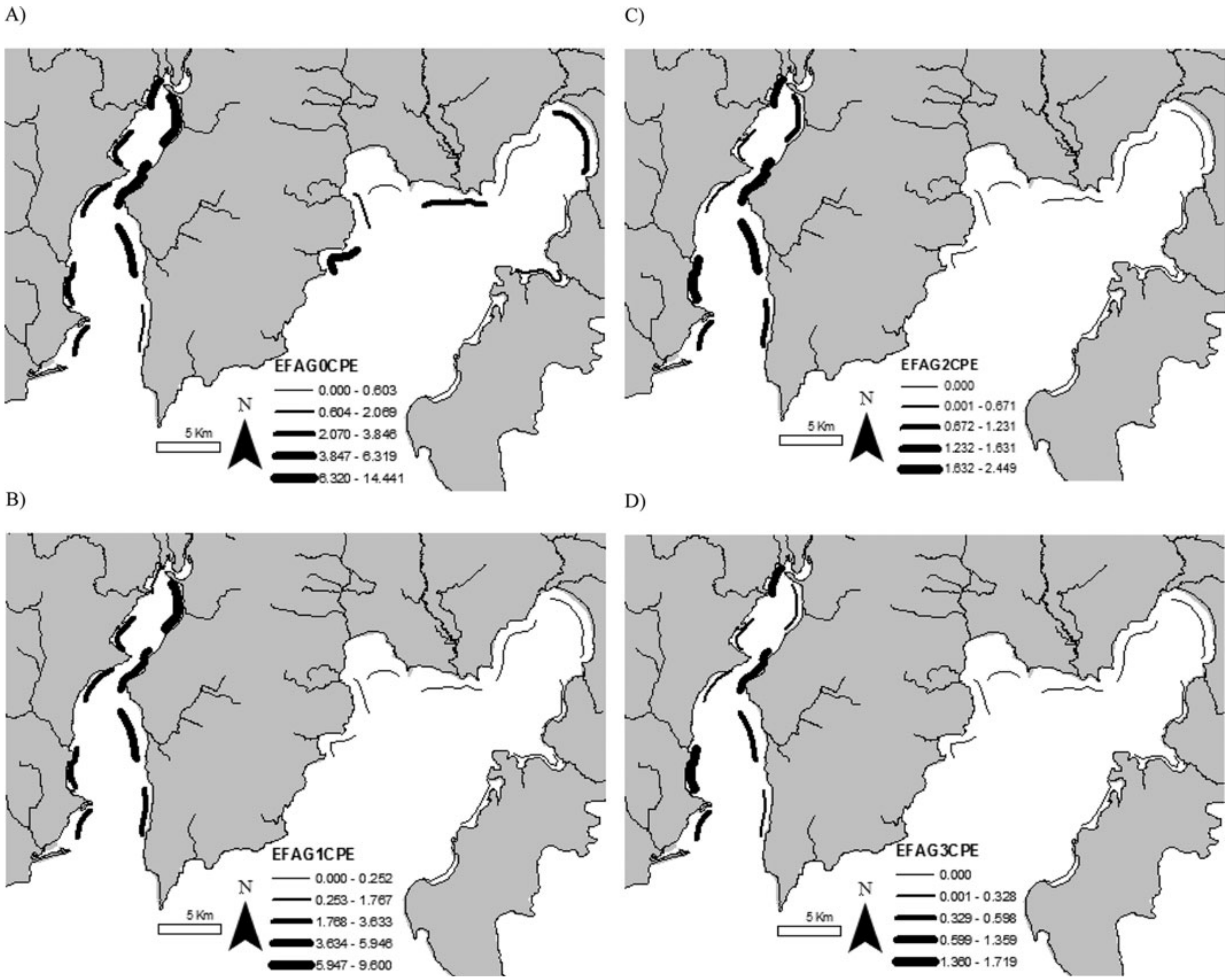


FIGURE 4. Mean electrofishing catch per hour by location for **(A)** age-0, **(B)** age-1, **(C)** age-2, and **(D)** age-3 Walleyes during 2004–2009.

rigorous conditions for Walleye reproduction and recruitment. River-spawning habitats are marginal in comparison to those available in LBDN, and shoreline spawning areas are generally more exposed to high wave action, offering less protection for eggs and fry. In addition, the availability of food items for shoreline-spawned Walleye fry may have changed due to invasive dreissenid mussels (Dettmers et al. 2003; MacWilliams 2013). Nevertheless, springtime Walleye angling in BBDN is typically concentrated in the northernmost portions of the bay where the two largest tributaries (the Sturgeon and Fishdam rivers) enter the bay. Deeper habitats, which provide the low-light conditions preferred by Walleyes, are generally well offshore in southern BBDN and potentially less accessible to small-boat anglers.

I identified several factors that limit the findings of this study. The field sampling targeted the shallower (less than 7-m-deep) shoreline areas of each bay, and since I randomly selected areas for gillnetting and electrofishing, the results generally apply to

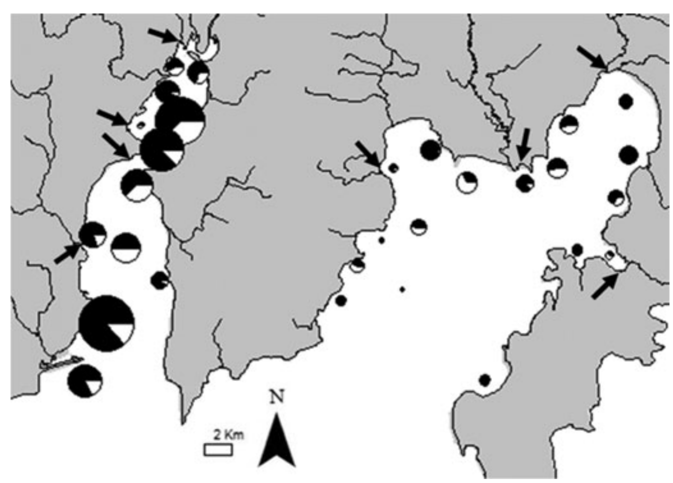


FIGURE 5. Relative gill-net catch per unit effort (pie size) for age-0 to age-3 Walleyes and contributions from hatchery (white) and natural (black) reproduction. The arrows point to stocking locations.

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

TABLE 4. Model results relating to Walleye growth, condition, and relative survival. Shown are (1) *P*-values from ANOVA models of the effects of the year sampled, bay (LBDN or BBDN), and origin (hatchery or wild) on the mean length at age of age-0 to age-3 Walleyes; (2) *P*-values from ANCOVA models examining the effects of origin and total length on the total weight of individual Walleyes; and (3) *P*-values from ANOVA models of the effects of age and year-class on the percent wild for supplementally stocked year-classes of Walleyes in Little Bay de Noc; N = the total number of samples used in the analysis.

Age-class	Source of variation	F	P	df
	Mean length			
Age 0 (N = 1,290)	Year	127.05	<0.001	1, 1,286
	Bay	259.85	<0.001	1, 1,286
	Origin	117.41	<0.001	1, 1,286
Age 1 (N = 986)	Year	47.84	<0.001	1, 982
	Bay	223.40	<0.001	1, 982
	Origin	2.61	0.106	1, 982
Age 2 (N = 426)	Year	0.74	0.391	1, 422
	Bay	61.99	<0.001	1, 422
	Origin	1.07	0.301	1, 422
Age 3 (N = 232)	Year	0.20	0.657	1, 228
	Bay	31.66	<0.001	1, 228
	Origin	2.34	0.128	1, 228
	Weight			
LBDN (N = 2,203)	Origin	2.11	0.147	1, 1,953
	Length	191.09	<0.001	140, 1,953
	Origin × length	0.73	0.981	108, 1,953
BBDN (N = 830)	Origin	0.40	0.529	1, 663
	Length	214.77	<0.001	108, 663
	Origin × length	0.65	0.980	57, 663
	Percent wild for stocked years			
LBDN (N = 12)	Age	19.12	0.002	1, 8
	Year-class	18.25	0.001	2, 8

these areas. I think that these data provide a reasonable picture of hatchery versus wild contributions to Walleye stocks for the entire bay, but the results may not apply to the deeper portions of the bays if hatchery Walleyes use shallow and deeper habitats differently than Walleyes of wild origin. I also assumed that hatchery Walleyes were well dispersed from stocking sites by the time of sampling (approximately 2.5 months after stocking) because I did not see obvious clumping of hatchery-origin Walleyes near stocking sites. However, this may not be the case, since fall fingerlings stocked into Minnesota lakes did not randomly mix with resident Walleyes for 2–3 years (Parsons et al. 1994). Increases in the percent wild for stocked year-classes of Walleyes at older ages in LBDN (Figure 7) suggest continued mixing of hatchery and wild fish over time or differences in survival between hatchery and wild Walleyes. I estimate that there was roughly 4% error in the age estimates, based on the percentage of Walleyes in unstocked year-classes that were attributed to hatchery sources. This could slightly increase or decrease my estimates of the percent wild contribution to year-classes and affect other age-based results. However, aging error would not substantially alter my overall findings regarding the contributions of hatchery fish, assessment-based catch rates of Walleyes, relationships between Walleye stocking and angler harvest rates, or the potential negative effects of supplementally stocking Walleyes in LBDN or BBDN. Finally, correlations between angler harvest rates and prior stocking helped identify situations in which the contributions of stocked Walleyes to the sport fishery were questionable (e.g., BBDN), but they have limited utility since the annual harvest and stocking data include several adjacent age-classes of Walleyes.

Management Implications

This study provided an evaluation of low-density supplemental stocking of hatchery-reared Walleyes in large bays

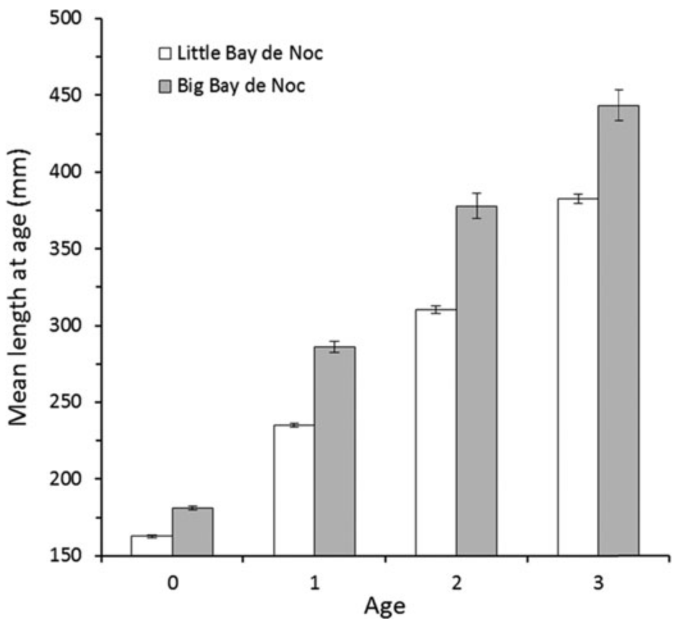


FIGURE 6. Marginal mean lengths at age of Walleyes in Big Bay de Noc and Little Bay de Noc. The error bars represent 2 SEs.

and open-water habitats of Lake Michigan. Stocked Walleye fingerlings were detectable in Walleye year-classes, persisted to older ages, and potentially contribute to the sport fishery in LBDN. In BBDN, stocked Walleyes were present in the fall at age 0, but the degree to which they persisted to older ages or contributed to the fishery was unclear. The lack of any obvious negative effects of supplemental stocking may relate to the low stocking densities used, and my finding that supplementally stocked year-classes were generally no more abundant than unstocked year-classes suggests that population densities were too low for negative intraspecific effects to occur (Li et al. 1996b). Given these findings, managers should weigh the trade-offs of supplemental stocking in larger waters (e.g., Great Lakes bays) when considering requests for hatchery Walleyes in smaller lakes and rivers, especially when stocking resources are limited.

Identifying rehabilitation targets is particularly challenging in Great Lakes waters due to ongoing environmental changes, most recently those associated with the invasion of dreissenid mussels. Walleye management objectives for LBDN include maintaining relatively stable Walleye stocks and recruitment (preferably self-sustaining) and a balance between predator and prey fishes (MDNR Fisheries Division 2012). Achieving this balance is a challenge since ongoing changes in key ecosystem components (e.g., water clarity, plankton levels, prey fish populations, and water temperatures) preclude the establishment of static equilibrium targets. To accommodate the changing environment, stocking decisions in LBDN are guided by an annual comparison of key assessment metrics (i.e., Walleye population abundance, the amount and sources of Walleye reproduction, and the predator–prey balance) to benchmark values computed from metric values for the previous 15 years (MDNR Fisheries Division 2012). The sliding time scale allows the rehabilitation targets to adjust to the changing environmental conditions over time.

Walleye rehabilitation efforts would benefit from a better understanding of the contribution of reef-spawning Walleyes to stocks in northern Green Bay. Walleyes planted into BBDN and LBDN are spawned from adults collected at the mouth of the Whitefish River in LBDN and are likely a river-spawning strain. Jennings et al. (1996) showed that river/reef spawning are genetically heritable traits. The strong homing tendencies of Walleyes to spawning rivers in northern Green Bay (Zorn and Schneeberger 2011) enable natural selection to shape each population over time, so that spawning Walleyes will make the best use of the spawning environment (river and estuary conditions) available to them (Kerr 2011). Reef-spawning Walleye strains may be needed to achieve rehabilitation success in BBDN, since it has abundant reef habitat but lacks rivers with suitable spawning habitat. In addition, Palmer et al. (2005) cautioned that stocking Walleyes that are not adapted to local spawning areas (river versus lake) can result in outbreeding depression, whereas stocking Walleyes adapted to local conditions may result in higher recruitment. Further work is needed to determine the relative contributions of river- and reef-spawning strains of Walleyes to the LBDN population, to assess the suitability of existing reef spawning habitats, and to identify reef-spawning strains that might be available for Walleye rehabilitation efforts in BBDN and similar waters.

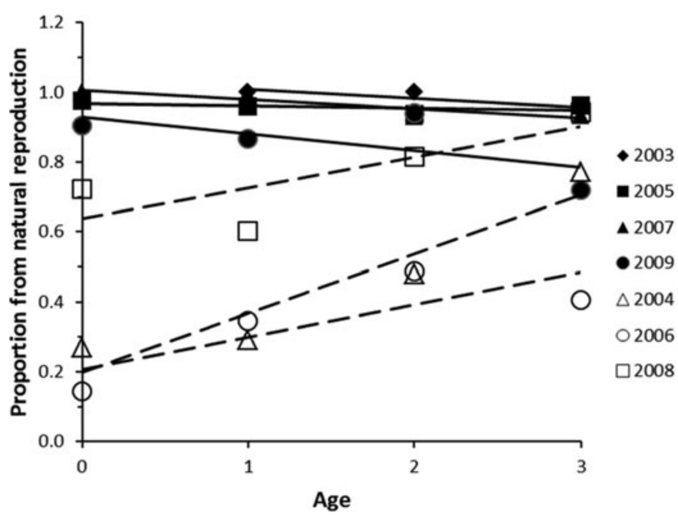


FIGURE 7. Proportion of the year-class attributed to natural reproduction by age (age 0 to age 3) for supplementally stocked (open symbols and dashed lines) and nonstocked year-classes of Walleyes (solid symbols and lines) in Little Bay de Noc.

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015

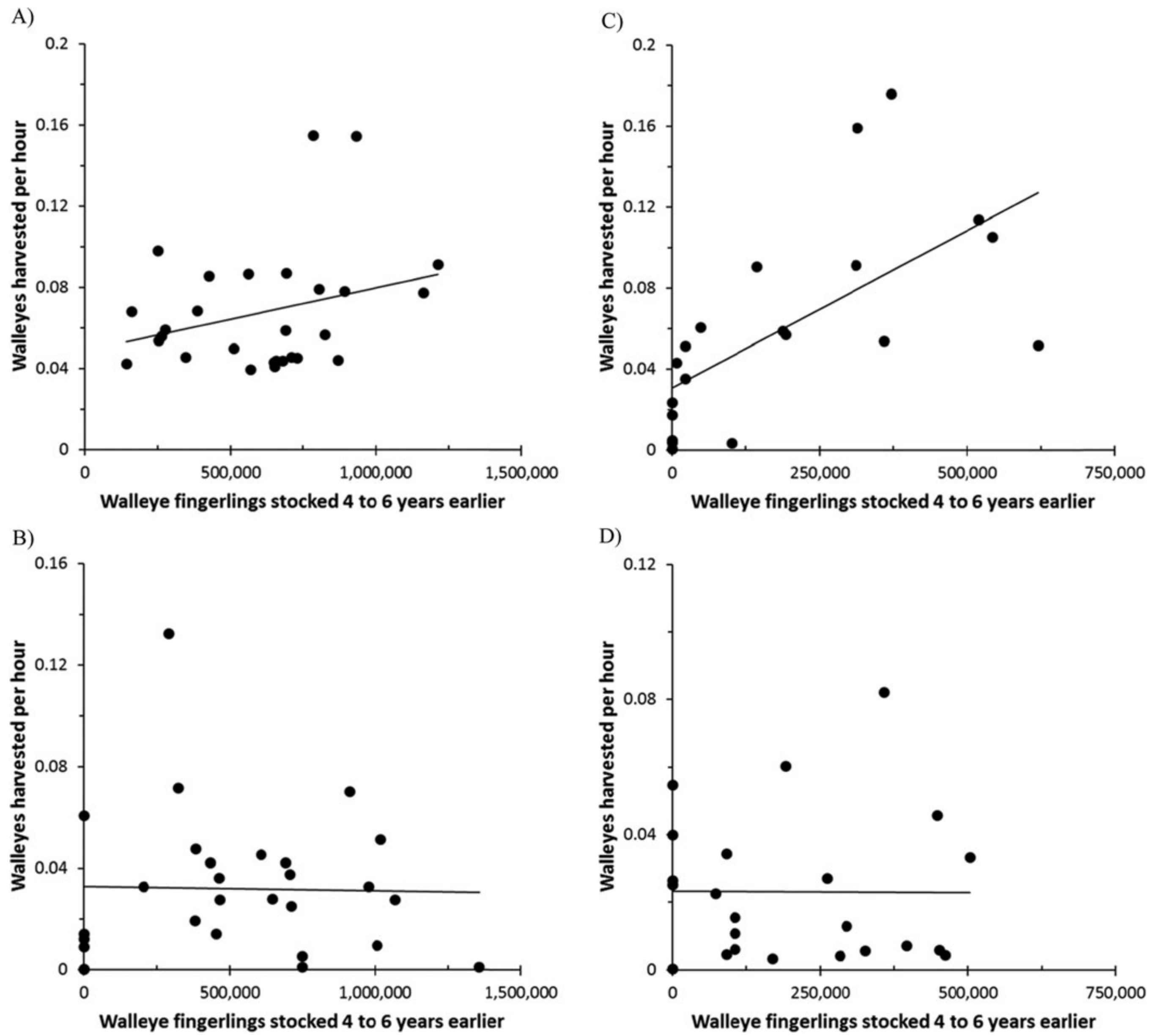


FIGURE 8. Relationships between estimates of annual angler harvest per hour of Walleyes for 1985–2012 and prior stocking in Lake Michigan at **(A)** LBDN, **(B)** BBDN, **(C)** the Menominee River, and **(D)** the Cedar River. The lines fit to the data points are for reference only.

ACKNOWLEDGMENTS

This study would not have been possible without the efforts of numerous field personnel who helped with data collection and sample processing. Staff from the Marquette Fisheries Research Station and Northern Lake Michigan Management Unit's Escanaba office, particularly K. Sanford, D. Traynor, G. Kleaver, R. Harrison, D. Kramer, and B. Mulzer played lead roles with field sampling. Walleye aging and data entry were performed by K. Sanford, and Walleye otoliths were examined by S. DeWitt and D. Fielder at the Alpena Fisheries Research Station. Statistical consultation was provided by D. Hayes and T. Wills. Helpful reviews of this manuscript were provided by D. Isermann, D. Kramer, B. Barton, and two anonymous reviewers. This study was supported with funds from the Federal Aid in Sport Fish Restoration Act (Study 521, Project F-80-R, Michigan), MDNR Fisheries Division.

REFERENCES

Dettmers, J. M., M. J. Raffenberg, and A. K. Weis. 2003. Exploring zooplankton changes in southern Lake Michigan: implications for Yellow Perch recruitment. Journal of Great Lakes Research 29:355–364.

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

Fielder, D. G. 2002. Sources of Walleye recruitment in Saginaw Bay, Lake Huron. North American Journal of Fisheries Management 22:1032–1040.

Fielder, D. G., J. S. Schaeffer, and M. V. Thomas. 2007. Environmental and ecological conditions surrounding the production of large year-classes of Walleye (*Sander vitreus*) in Saginaw Bay, Lake Huron. Journal of Great Lakes Research 33(Supplement 1):118–132.

Jennings, M. J., J. E. Claussen, and D. P. Philipp. 1996. Evidence for heritable preferences for spawning habitat between two Walleye populations. Transactions of the American Fisheries Society 125:978–982.

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.

Kampa, J. M., and M. J. Jennings. 1998. A review of Walleye stocking evaluations and factors influencing stocking success. Wisconsin Department of Natural Resources, Research Report 178, Spooner.

Kapuscinski, K. L., T. G. Zorn, P. J. Schneeberger, R. P. O'Neal, and B. T. Eggold. 2010. The status of Lake Michigan Walleye stocks. Great Lakes Fishery Commission Technical Report 69:15–70.

Kerr, S. J. 2008. A survey of Walleye stocking activities in North America. Ontario Ministry of Natural Resources, Peterborough.

Kerr, S. J. 2011. Stocking and marking: lessons learned over the past century. Pages 423–449 *in* B. A. Barton, editor. Biology, management, and culture of Walleye and Sauger. American Fisheries Society, Bethesda, Maryland.

Kerr, S. J., B. W. Corbett, D. D. Flowers, D. Fluri, P. E. Ihssen, B. A. Potter, and D. E. Seip. 1996. Walleye stocking as a management tool. Ontario Ministry of Natural Resources, Peterborough.

Laarman, P. W. 1978. Case histories of stocking Walleye in inland lakes, impoundments, and the Great Lakes: 100 years with Walleyes. Pages 254–260 *in* R. L. Kendall, editor. Selected coolwater fishes of North America. American Fisheries Society, Special Publication 11, Bethesda, Maryland.

Laarman, P. W., and J. C. Schneider. 1986. Walleye stocking experiments and fish population studies at Manistee Lake, 1972–84. Michigan Department of Natural Resources, Fisheries Research Report 1938, Ann Arbor.

Li, J., Y. Cohen, D. H. Schupp, and I. R. Adelman. 1996a. Effects of Walleye stocking on population abundance and fish size. North American Journal of Fisheries Management 16:830–839.

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

MacWilliams, R. D. 2013. Limitations of larval Walleye (*Sander vitreus*) production in Michigan's Inland Waterway. Master's thesis. Michigan State University, East Lansing.

MDNR (Michigan Department of Natural Resources). 2004. Stocking guidelines for various species of fish. Chapter 5 *in* J. L. Dexter Jr. and R. P. O'Neal, editors. Michigan fish stocking guidelines II, with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 32, Ann Arbor.

MDNR (Michigan Department of Natural Resources) Fisheries Division. 2012. Walleye management strategy for Little Bay de Noc, Lake Michigan. Available: http://www.michigan.gov/documents/dnr/LBDN_Walleye_management_strategy-_Jul2012_FINAL_391363_7.pdf. (June 2015).

O'Neal, R. P. 1997. Muskegon River watershed assessment. Michigan Department of Natural Resources, Special Report 19, Ann Arbor.

Palmer, G. C., B. R. Murphy, and E. M. Hallerman. 2005. Movements of Walleyes in Claytor Lake and the upper New River, Virginia, indicate distinct lake and river populations. North American Journal of Fisheries Management 25:1448–1455.

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., D. L. Pereira, and P. D. Eiler. 1994. Evaluation of Walleye fingerling stocking in three west-central Minnesota lakes. Minnesota Department of Natural Resources Section of Fisheries Investigational Report 435.

Schneider, J. C., T. J. Lychwick, E. J. Trimberger, J. H. Peterson, R. O'Neal, and P. J. Schneeberger. 1991. Walleye rehabilitation in Lake Michigan, 1969–1989. Great Lakes Fishery Commission Special Publication 91-1: 23–62.

USFWS (U.S. Fish and Wildlife Service). 2011. Decision and finding of no significant impact for reducing double-crested cormorant damage through an integrated wildlife damage management program in the state of Michigan. Available: http://www.fws.gov/midwest/nepa/MICormorantNEPA/documents/WSFinalcombinedFONSI-04.pdf. (June 2015).

Zorn, T. G., and P. J. Schneeberger. 2011. Habitat and fish community changes in the Michigan waters of Green Bay, 1988–2005. Michigan Department of Natural Resources, Fisheries Research Report 2096, Ann Arbor.

Downloaded by [Troy G. Zorn] at 05:39 24 June 2015