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Jonathan A. Freedman [a], R. John H. Hoxmeier [a c], Lisa M. Einfalt [a], Ronald C. Brooks [b d] & David H. Wahl [a]

[a] Illinois Natural History Survey, Kaskaskia Biological Station, 1235 County Road 1000N, Sullivan, Illinois, 61951, USA

[b] Fisheries and Illinois Aquaculture Center, Southern Illinois University, 1125 Lincoln Drive, Carbondale, Illinois, 62901, USA

[c] Minnesota Department of Natural Resources, 1801 South Oak Street, Lake City, Minnesota, 55041, USA

[d] Kentucky Department of Fish and Wildlife Resources, Fisheries Division, 1 Sportsman's Lane, Frankfort, Kentucky, 40601, USA

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ARTICLE

Largemouth Bass Predation Effect on Stocked Walleye Survival in Illinois Impoundments

Jonathan A. Freedman,* R. John H. Hoxmeier,[1] and Lisa M. Einfalt
Illinois Natural History Survey, Kaskaskia Biological Station, 1235 County Road 1000N, Sullivan, Illinois 61951, USA

Ronald C. Brooks[2]
Fisheries and Illinois Aquaculture Center, Southern Illinois University, 1125 Lincoln Drive, Carbondale, Illinois 62901, USA

David H. Wahl
Illinois Natural History Survey, Kaskaskia Biological Station, 1235 County Road 1000N, Sullivan, Illinois 61951, USA

Abstract

Survival of stocked fish can be mediated by biotic factors such as size and species, predators, and prey, and abiotic influences such as temperature and habitat. Walleyes *Sander vitreus* are numerically among the most stocked fish in the USA, yet stocking success of this species is highly variable. We examined the effects of predation by largemouth bass *Micropterus salmoides* on walleyes across 77 stocking events in 10 Illinois impoundments. Predation mortality was assessed by examining diets of largemouth bass for up to 21 d post walleye stocking. Of 8,591 largemouth bass diets examined, 2.0% contained walleye, corresponding to 4.3% walleye mortality attributable to largemouth bass predation. Largemouth bass predation was greatest within 24 h of stocking, and no predation was observed after 14 d. Predation mortality and fall CPUE of walleyes were related to largemouth bass density; however, we found no relationship between predation mortality and fall CPUE of walleyes. Our results suggest that predation by largemouth bass, a widespread and abundant predator, has a negligible effect on walleye stocking success in Illinois impoundments.

Stocking is an important management tool for maintaining recreational fisheries and for replenishing declining populations of native species. For instance, over 10^9 walleye *Sander vitreus* were stocked into 34 U.S. states in 2004 (Halverson 2008), including 25 million walleye stocked into Illinois lakes by the Illinois Department of Natural Resources (unpublished data). Hatchery production is an expensive process, and depending on species, stocking size, and stocking environment, stocking small fish allowed to grow to harvestable size in the wild, or stocking larger fish that have been reared longer in captivity may maximize the tradeoff between relative survival and production cost (Santucci and Wahl 1993; Santucci et al. 1994; Brooks et al. 2002). Species-specific and lake-specific information on relative poststocking survival is therefore needed to inform stocking and management decisions.

Many factors can influence survival of stocked fish, including population structure of both prey and predators. Density and size of prey can affect growth and survival of stocked fish (Carline

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*Corresponding author: freedjon@illinois.edu

[1] Present address: Minnesota Department of Natural Resources, 1801 South Oak Street, Lake City, Minnesota 55041, USA.

[2] Present address: Kentucky Department of Fish and Wildlife Resources, Fisheries Division, 1 Sportsman's Lane, Frankfort, Kentucky 40601, USA.

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et al. 1986; Wahl et al. 1995; Kolar et al. 2003; Hoxmeier et al. 2004; Fayram et al. 2005; Hoxmeier et al. 2006). When fish are initially stocked into a system, they may become easy prey for predators due to disorientation and stress. Most hatcheries rear fish in plain concrete tanks or ponds, although fish reared in enriched tanks may have higher poststocking feeding and survival rates (Salvanes and Braithwaite 2006; Strand et al. 2010). Moreover, fish are often stocked at one location in a lake (e.g., a boat ramp) and may have limited dispersal from this site, thus potentially creating artificially high densities of naïve prey and increasing predator feeding efficiency (Parsons and Pereira 1997; Buckmeier and Betsill 2002). Stocked fish may therefore be more vulnerable to predation than natural populations, with highest predation effects within 30 d of stocking (Carline et al. 1986; Wahl and Stein 1989).

Predation on stocked fish is highly variable and may depend on the species and size of fish stocked, as well as predator community composition and size structure (Fayram et al. 2005; Hoxmeier et al. 2006). Spiny-rayed fishes are less vulnerable to predation than soft-rayed species (Wahl 1995; Einfalt and Wahl 1997; Sass et al. 2006). Species such as walleye (Laarman 1978; Santucci and Wahl 1993; Wahl 1995; Fayram et al. 2005), saugeye (sauger *S. canadensis* × walleye; Stahl et al. 1996), and largemouth bass *Micropterus salmoides* (Miranda and Hubbard 1994; Diana and Wahl 2009) thus have lower predation mortality than esocids (Carline et al. 1986; Wahl and Stein 1989; Wahl 1995) and salmonids (Cartwright et al. 1998; Hyvärinen and Vehanen 2004). Likewise, larger size at stocking has generally been linked to higher survival for a number of species (e.g., Laarman 1978; Santucci et al. 1994; Fayram et al. 2005; Diana and Wahl 2009), although some studies of walleye have found that environmental and biological conditions of stocked lakes can be more important than size at stocking (Laarman 1978; Hoxmeier et al. 2006). Size-selective mortality is linked to effective predator density (i.e., the number of potential predators capable of consuming the prey; Carline et al. 1986). Hence, larger size at stocking can reduce the effective predator density and, thus, predation pressure, even while total predator density remains constant.

The relative importance of predation mortality in mediating walleye stocking success is not well understood. While numerous studies have examined predation mortality in other species, including some with walleye, with few exceptions most have drawn conclusions from five or fewer lakes sampled over short periods (1–2 years). A notable exception was a study of walleye stocking in multiple lakes across 11 years in Wisconsin that found survival of stocked walleyes to be inversely correlated with largemouth bass abundance (Fayram et al. 2005). Our objectives were to determine whether predation by largemouth bass (1) affected walleye survival and stocking success across a number of stocking events, and (2) was mediated by walleye size-at-stocking. We hypothesized that although largemouth bass would not comprise a major source of walleye mortality, walleye mortality would be positively correlated with predator density. We also expected that largemouth bass would prey more heavily on smaller sizes of stocked fish.

METHODS

Walleyes were stocked into 10 Illinois impoundments ranging in surface area from 6 to 379 ha, for a total of 77 stocking events from 1991 to 1997 (Table 1). Impoundments varied in

TABLE 1. Summary of walleye stocking (May–August 1991–1997) in 10 Illinois reservoirs. Walleyes were stocked as small fingerlings (45 mm TL) at a target density of 90/ha or as large fingerlings (100 mm TL) at 65/ha. Largemouth bass density was limited to the number (*N*) large enough to consume the stocked walleyes.

Reservoir (ha)	Stocking size (mm)	Stocking events (*N*)	Stocking density (*N*/ha)	Walleye CPUE (*N*/h)	Largemouth bass density (*N*/ha)
Bloomington (250)	34–53	7	10–102	0.3–22.9	7–16
East Fork (379)	43–50	3	99–124	0.3–21.4	6–25
George (68)	36–53	4	98–123	0.04–3.0	7–17
Le Aqua Na (16)	39–47	6	39–109	0.4–8.2	7–33
	87–117	7	62–91	0.0–15.2	7–33
Pierce (66)	34–55	10	49–127	0.9–62.5	2–26
Randolph Co. (26)	38–50	5	100	0.0–1.7	23–356
	96–118	5	62–117	0.0–0.3	23–356
Ridge (6)	34–37	2	117–125	0.0–6.1	69–158
	95–104	3	67–117	0.0–2.4	49–123
Sam Dale (78)	32–52	8	50–110	0.0–2.3	26–152
Sara (237)	41–56	7	42–112	0.0–2.0	8–108
Sterling (53)	35–48	5	51–90	1.6–18.3	2–8
	93–106	5	35–68	1.0–23.1	1–8

productivity (although all were eutrophic) and predator densities (see Hoxmeier et al. 2006). Largemouth bass, a known predator of juvenile walleye (Santucci and Wahl 1993; Fayram et al. 2005; Hoxmeier et al. 2006), were the most abundant piscivore across all study lakes (density range, 1–356 /ha). Other predators present in the impoundments included channel catfish *Ictalurus punctatus*, white bass *Morone chrysops*, and adult walleyes. Prey fish communities were predominated by bluegill *Lepomis macrochirus* and gizzard shad *Dorosoma cepedianum* (Hoxmeier et al. 2006). No natural reproduction of walleyes was known to occur in study impoundments. Densities and composition of aquatic vegetation communities were variable across impoundments and years, but consisted primarily of pondweed *Potomogeton* spp., coontail *Certatophyllum demersum*, water milfoil *Myriophyllum* spp., and naiad *Najas* spp.

Walleyes were obtained from the Jake Wolf Memorial Fish Hatchery (Manito, Illinois) and the LaSalle Fish Hatchery (Marseilles, Illinois). Fish were stocked as small (mean total length [TL] = 44.8 mm; 57 stocking events, May–June) or large (mean = 100.3 mm TL; 20 stocking events, July–August) fingerlings. Small fingerlings were marked by immersion in 500 mg/L oxytetracycline (OTC) for 6 h prior to stocking (Brooks et al. 1994). Large walleyes were marked by clipping either the right or left pelvic fin in alternating years. Clipping occurred at the hatchery 2–7 d prior to stocking; fish were held for recovery in raceways and to account for any handling mortality. Fish were transported to impoundments in oxygenated hauling tanks, acclimated to impoundment temperatures by transferring impoundment water into the hauling tanks until temperatures were equalized (Clapp et al. 1997), and stocked at one nearshore location, typically at the boat ramp. We measured 50 individuals (TL; mm) for each stocking event. Target stocking densities were 90 small walleyes/ha or 65 large walleyes/ha, but this varied with fish availability in some instances (Table 1).

Predation on walleyes by largemouth bass was assessed by examining diets of largemouth bass diets that were captured during nighttime shoreline electrofishing of the entire impoundment perimeter on the day of stocking and at 1, 2, 3, 5, 7, 10, 14, and 21 d poststocking. The number of stomachs sampled was standardized by sampling effort, which is related to predator density. Gastric lavage (Foster 1977) was used to recover dietary items from each largemouth bass, and all prey items were identified. Based on prior studies at temperatures similar to those we encountered, we assumed that largemouth bass stomach contents represented 1 d of feeding and that walleyes could be identified in the stomach up to 24 h after consumption (Hunt 1960; Beamish 1972; Wahl and Stein 1989; Santucci and Wahl 1993). Walleyes recovered from stomachs were identified by morphological characteristics and were examined for marks. Any fish too digested to be identified was recorded as unidentified fish prey.

Predation on stocked walleyes is highest within the first 24–48 h after stocking (Santucci and Wahl 1993). So, if no walleyes were present in diets for any two consecutive sampling periods after a stocking, we assumed that largemouth bass predation on walleye was negligible, and no further sampling was performed for that impoundment. To determine largemouth bass densities in the impoundments, we used mark–recapture data collected using nighttime shoreline electrofishing every 1–2 weeks in each impoundment during late summer and fall (August–November) after walleye stocking. All largemouth bass were measured, weighed, and examined for fin clips indicating prior capture; fins were clipped if no prior clip was present. We used Schnabel population estimates to determine the population density of largemouth bass in each impoundment. Estimates of walleye mortality due to largemouth bass predation were estimated by

$$Y_i = \sum_{j=1}^{d} \frac{a_j}{b_j} \cdot x,$$

where a is the number of walleyes recovered from b largemouth bass stomachs during sample j, x is the estimated effective population of largemouth bass of the size (TL) capable of consuming each size-class of walleye (1.75 times prey TL; Santucci and Wahl 1993; Wahl 1995), and d is the number of days poststocking (Carline et al. 1986; Wahl and Stein 1989). Estimates of walleye mortality due to largemouth bass predation between stocking dates were calculated using linear interpolation.

Electrofishing surveys are commonly used for walleye population estimates (Fayram et al. 2005; Hoxmeier et al. 2006); survival of stocked walleyes was therefore also estimated using nighttime shoreline electrofishing surveys conducted every 2 weeks during the fall (September–November). All walleyes caught were measured, weighed, examined for the presence of fin clips, and subsampled (frozen) for later examination of OTC marks. Otoliths were later removed and examined for OTC marks in the laboratory, using a compound microscope with a 100-W ultraviolet light source, a 450–490-nm excitation filter and 515-nm barrier filter, and a 510-nm dichroic mirror. Due to an insufficient number of walleye recaptures at many impoundments, we were unable to use Schnabel population estimates for comparisons among stocking events, so CPUE (number/h of electrofishing) was used instead, which has been shown to be highly correlated to number of walleye/ha (Hoxmeier et al. 2006).

We examined differences in predation mortality in four impoundments that were stocked over 2–6 years with both small and large fingerlings (Table 1). We tested for differences using a mixed-effects-model likelihood-ratio test (LRT) in the lme4 package (Bates et al. 2011) implemented in R 2.14 (R Development Core Team 2008) to account for temporal and spatial pseudoreplication. Percent predation mortality was the response variable, years and impoundments were random variables, and stocking size was the fixed variable. Relationships between largemouth bass density and fall walleye CPUE and walleye predation mortality and fall walleye CPUE were tested using a two-dimensional Kolmogorov–Smirnoff test (2DKS), implemented

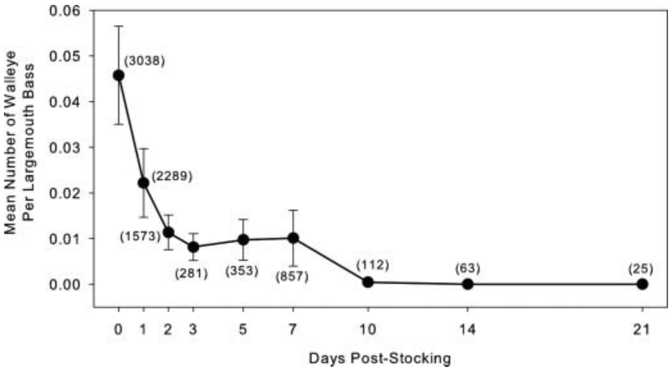

FIGURE 1. Mean number (± SE) of walleyes recovered from largemouth bass stomachs following 77 stocking events across 10 reservoirs and 7 years in Illinois. Numbers of largemouth bass stomachs examined are in parentheses.

using big2dks software (Garvey et al. 1998). The 2DKS test detects patterns in bivariate data, where D_{BKS} is the maximum difference between the observed and expected proportions and $P < 0.05$ indicates that the distribution is nonrandom.

RESULTS

Approximately 500,000 small and 33,000 large walleye fingerlings were stocked into the 10 impoundments during the 7-year study. We sampled the diets of 8,591 largemouth bass stomachs. The mean number of diets per stocking event was 110.7 (SD, 94.6), and we recovered 132 of the small and 42 of the large stocked walleyes. Overall, 2.0% of largemouth bass stomachs contained walleye, and total mortality of stocked walleyes due to largemouth bass predation was 4.3%. We did not detect largemouth bass predation on walleyes in 42 (54.5%) stockings. Predation on walleyes by largemouth bass was greatest on the day of stocking: 0.046 walleyes/stomach and 3.9% of the stomachs examined contained one or more walleyes (Figure 1). Predation declined exponentially over the next 21 d, with the next highest predation rates occurring on day 1 (when 1.3% of largemouth bass stomachs contained walleyes) and day 3 (when 1.8% did). By 14 d poststocking we detected no predation by largemouth bass on walleye (Figure 1).

In impoundments stocked with both small and large fingerlings, mean (SD) estimated mortality of small walleyes was 6.2% (23.4) and ranged from 0% to 100%, the majority being less than 19% (Figure 2). Mean (SD) mortality due to predation of large walleyes was 7.6% (15.6), and ranged from 0.0% to 56.9%. There were no differences between mortality due to largemouth bass predation between small and large walleyes stocked into the same impoundments (LRT = 0.043, $P = 0.84$).

Despite low largemouth bass predation on stocked walleyes, largemouth bass density was related to walleye predation mortality (2DKS, $X = 1.59$, $Y = 0.48$, $D_{BKS} = 0.16$, $P = 0.0002$; Figure 2a). Although many stocking events resulted in no survival of stocked walleyes to the fall (mean [SD] survival = 2.6% [6.0]; mean CPUE = 5.5 [9.8]), the 2DKS test detected a nonrandom relationship between largemouth bass density and walleye fall CPUE, lower walleye CPUE occurring below a density of 24.9 largemouth bass/ha ($X = 24.94$, $Y = 1.81$, $D_{BKS} = 0.14$, $P = 0.0002$; Figure 2b). There was no relationship, however, between walleye predation mortality and walleye fall CPUE ($X = 1.85$, $Y = 2.23$, $\mathrm{D_{BKS}} = 0.05$, $P = 0.37$; Figure 2c).

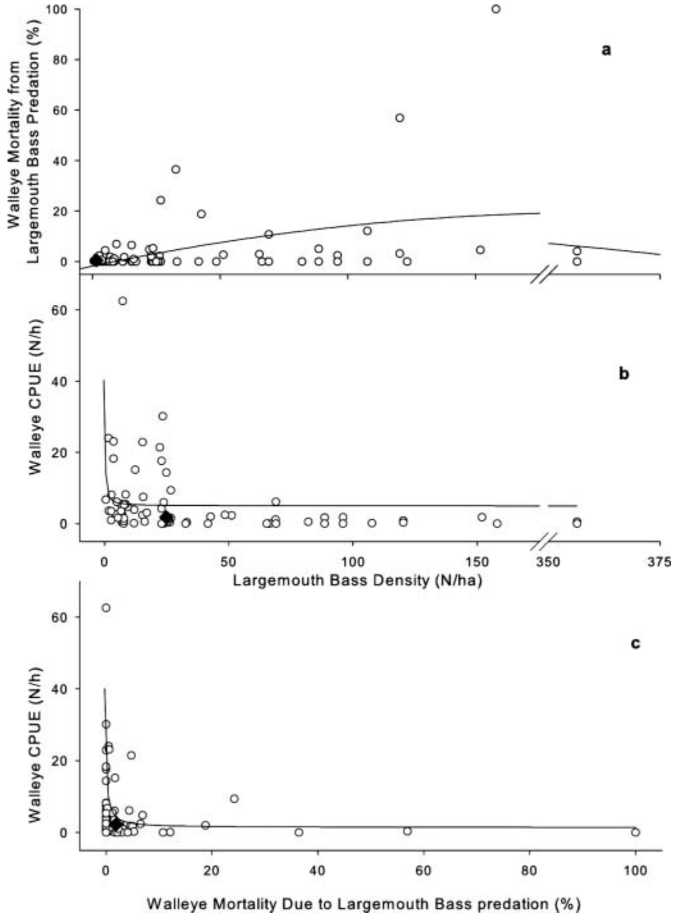

FIGURE 2. (**a**) Largemouth bass predation mortality on stocked walleyes, (**b**) fall CPUE for stocked walleyes as functions of largemouth bass effective predator densities, and (**c**) fall walleye CPUE as a function of walleye mortality due to largemouth bass predation. Polynomial best fits are represented by solid lines. Values producing D_{BKS} (two-dimensional Kolmogorov–Smirnoff test) are represented by solid diamonds.

DISCUSSION

Largemouth bass predation on walleye fingerlings was highest immediately after stocking, and we detected no predation mortality after 14 d. Timing of predation is consistent with an earlier study that found 76% of walleyes eaten by largemouth bass in Ridge Lake, Illinois, were consumed within 48 h (Santucci and Wahl 1993). Predation losses of saugeyes stocked into reservoirs in Ohio similarly approached zero after 14 d, although residual mortality due to predation was assumed to occur for an additional 6 weeks (Stahl et al. 1996). Predation on a number of other stocked fishes, including muskellunge

Esox masquinongy (Wahl and Stein 1989), tiger muskellunge muskellunge × northern pike *E. lucius* (Carline et al. 1986) and channel catfish (Santucci et al. 1994) is also highest soon after stocking. Our study focused on largemouth bass because other studies have found them to be the primary source of predation mortality on stocked walleyes (Santucci and Wahl 1993; Fayram et al. 2005). However, other predators such as channel catfish and white bass that were present in lower numbers in some lakes may have also contributed to the low survival of stocked walleyes. Stocked fish may also experience losses through other mechanisms, such as thermal or transport stress, low feeding rates, emigration, or natural mortality (Wahl et al. 1995). The combined effects of these mortality sources may reduce densities of stocked fish to the point where predators switch to alternative prey (Carline et al. 1986; Santucci and Wahl 1993).

We found no differences between predation rates on small and large walleye fingerlings stocked into the same impoundments. Previous studies on a number of other introduced fishes have generally found higher predation rates on small fish (Carline et al. 1986; Storck and Newman 1988; Santucci and Wahl 1993; Santucci et al. 1994; Diana and Wahl 2009). Santucci and Wahl (1993), however, found mean mortality due to largemouth bass predation increased from 6% for 57-mm walleyes to 17% for 140-mm walleyes stocked into a small Illinois impoundment, but was 0% for 205-mm walleyes. We expected that higher effective predator densities would result in higher mortality of small fish; however, effective predator densities were similar for both size-classes. This may have been due to size-biased sampling because most largemouth bass captured during electrofishing surveys were capable of consuming either size of walleye (>175.5-mm mean TL). The lack of a size-at-stocking effect on walleye predation mortality may have also been mediated by a number of other factors, including seasonal differences.

Timing of stocking may have influenced our results since large walleye fingerlings were stocked in midsummer, whereas small fingerlings were stocked in late spring and early summer. Large walleye fingerlings may have represented a more optimal prey in late summer when other potential prey may have exceeded gape limitation for the predators, while small walleye fingerlings in early summer may have been suboptimal prey relative to other potential prey present in the systems. Additionally, in the summer there may be increased abundance of alternative prey such as gizzard shad, and thus lower predation pressure on the stocked fish. Higher predation mortality of fish stocked in summer than autumn has been attributed to several factors related to higher temperatures: increased thermal stress, poikilothermic predators having higher metabolic rates (and thus higher feeding rates), and predators and prey (including stocked fish) concentrated in inshore areas due to thermal stratification (Carline et al. 1986).

There was no significant relationship between walleye predation mortality and walleye fall CPUE, although lower fall CPUE was correlated with largemouth bass densities above 24.9 fish/ha. A bioenergetics model of Whitefish Lake, Wisconsin, estimated that largemouth bass consumed all stocked walleyes and, in general, found high predation effects of largemouth bass on walleye (Fayram et al. 2005). Largemouth bass may also have affected walleye survival through nonconsumptive effects (Peckarsky et al. 2008), such as altering walleye behavior and growth or through competition for food resources (Parkos and Wahl 2010). Bluegills and gizzard shad were abundant in many of our impoundments, potentially competing for food with juvenile walleyes. Gizzard shad abundance is correlated with bluegill abundance, where they may act as alternative prey for largemouth bass (Aday et al. 2003). Similarly, availability of alternative prey may mediate largemouth bass predation on stocked walleyes.

Density-dependent relationships have been noted between largemouth bass populations and predation rates on stocked esocids (Carline et al. 1986; Szendrey and Wahl 1996) and walleye (Santucci and Wahl 1993). However, these studies were performed in a limited number of lakes and correlations may thus have been influenced by relatively small sample sizes. Our results across 77 impoundment-years suggest that there is not a density-dependent relationship between largemouth bass populations and survival of stocked walleyes. Fall CPUE of walleyes, however, did not exceed 10/h in any impoundment-year when largemouth bass density was >25/ha. Long-term studies across a number of lakes are necessary to determine if similar patterns exist for other species and in other geographic areas.

MANAGEMENT IMPLICATIONS

Predator density can be an important consideration when stocking fish. For walleyes stocked into Illinois impoundments, however, it appears to play a relatively minor role in influencing walleye survival. Fall survival was <3%, while mortality due to largemouth bass predation was <1%; so, other factors are probably more important in determining stocking success and failure in our studied impoundments. Those 10 impoundments varied in size, but were all characterized as eutrophic to hypereutrophic and, thus, generally had high levels of food resources. Our results from Illinois may be applicable to other Midwestern and moderate-latitude lakes and impoundments, especially those with strong prey fish populations, but should be confirmed in systems in other geographic regions across productivity levels and predator and prey fish communities. Abundant prey may increase competition with walleye fingerlings and thus contribute to low survival of stocked fish, but abundant prey may also moderate predator effects. Modification of rearing habitat increases survival of stocked fish and should be implemented when possible to improve stocking success (Salvanes and Braithwaite 2006; Strand et al. 2010). Size at stocking of walleyes has been shown to be correlated with survival (Santucci and Wahl 1993; Brooks et al. 2002); however, this does not appear to be linked with predator density.

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