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FEATURED PAPER

Using Radiotelemetry to Evaluate Poststocking Survival and Behavior of Large Fingerling Walleye in Three Iowa, USA, Lakes

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Abstract
Stocking Walleye *Sander vitreus* is a common management tool to augment populations where natural reproduction is limited. Some hatcheries have progressively raised larger fingerling Walleye to improve poststocking survival; however, little is known about the poststocking survival and behavior of large fingerling Walleye. We sought to evaluate the poststocking daily apparent survival, depth use, dispersal, and home range size of large fingerling Walleye (>200 mm TL) in three Iowa, USA, lakes. Walleye (209–265 mm; *n* = 15 per lake [45 fish total]) were implanted with radio tags, stocked on October 26–30, 2017, and tracked until May 30, 2018. Cormack–Jolly–Seber recapture models estimated that Walleye apparent survival increased with days poststocking and fish length, resulting in 76% (95% CI = 44–89%) cumulative survival by May. Walleye in Brushy Creek Lake were located in deeper water (mean ± SE = 5.1 ± 0.2 m) than those in Big Creek Lake (3.3 ± 0.2 m) or East Okoboji Lake (1.7 ± 0.1 m), but depth use did not vary with days poststocking. Walleye dispersed an average of 1,355 ± 234 m within 13 d across all lakes, with home range size being larger in Big Creek Lake (mean ± SE = 67.9 ± 21.7 ha) than in Brushy Creek Lake (15.5 ± 15.7 ha) or East Okoboji Lake (31.0 ± 14.0 ha). Our results indicate that Walleye poststocking survival is high overall, with most mortality occurring within 20 d as Walleye are dispersing, suggesting that managers should focus on improving survival during this critical period to improve stocking success.

Walleye *Sander vitreus* is a popular sport fish throughout North America, as nearly 4 million anglers spent 75 million d fishing for Walleye during 2016 (USFWS and U.S. Census Bureau 2018). Maintaining quality Walleye populations throughout North America is a goal for many management agencies. Fish populations are largely regulated through recruitment patterns (Ricker 1975); however, Walleye recruitment is declining in some locations (Hansen et al. 2017; Rypel et al. 2018), whereas Walleye cannot naturally reproduce or their recruitment is limited in other locations (Mitzner 2002; Reed and Staples 2017; Koch et al. 2018). Although the reasons for poor recruitment are not clear, potential mechanisms that have been hypothesized include competition or predation (Fayram et al. 2005; Fielder et al. 2007), climate variability (Beard et al. 2003; Hansen et al. 2017), and habitat loss (Hansen et al. 2019). Regardless of the mechanism, the lack of Walleye recruitment is concerning, as it creates problems for sustainable Walleye fisheries.

Throughout the species' range, stocking of Walleye is a management tool used to supplement and maintain populations (Kerr 2011). In 2006, nearly 1×10^9 Walleye fry, fingerlings, and advanced fingerlings were stocked in 36 states in the USA and five Canadian provinces (Kerr 2011). Survival of fish during early life stages is generally

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thought to increase with size due to the “bigger is better” hypothesis wherein larger individuals experience lower starvation and predation rates (Rice et al. 1987; Miller et al. 1988). Walleye stocking programs often rely on stocking large numbers of fry (~10 mm TL); this strategy can be successful in some instances (e.g., Logsdon et al. 2016) but is more often unsuccessful in many situations (Laarman 1978; Mitzner 2002). Large fingerling Walleye (>200 mm TL) are also commonly stocked (Kerr 2011; Summerfelt et al. 2011); they may be less vulnerable to starvation and predation due to their size and can successfully produce year-classes when fry stockings fail (Mitzner 2002; Hoxmeier et al. 2006; Kampa and Hatzenbeler 2009; Kerr 2011) while also being more cost effective to stock than fry (Santucci and Wahl 1993). Despite the perceived benefits of stocking larger Walleye, larger fingerlings are more difficult and expensive to produce and hatcheries can only produce limited numbers of large fingerlings compared to smaller individuals through intensive culture or pond rearing techniques (Fenton et al. 1996; Summerfelt et al. 2011). The contribution of large fingerling Walleye to adult populations can also be small in some instances (Olson et al. 2000; Kerr 2011), and the fate of these stocked individuals is often unknown. A better understanding of the fate and behavior of stocked fingerling Walleye would be beneficial for improving the success of stocking.

Stocked fish experience a survival bottleneck during the first several weeks poststocking, as they must develop behaviors that allow them to locate food while avoiding predators (Brown and Laland 2001; Pouder et al. 2010; Thompson et al. 2016). An understanding of poststocking behaviors (e.g., depth use, dispersal, and home range) across a range of lakes with variable habitat and predator assemblages could provide insights into fish acclimation to natural environments under a range of conditions. Telemetry is a useful tool for understanding behavior and survival of fish (Hightower and Harris 2017) and is commonly used for adult Walleye (e.g., Eberts et al. 2018; Faust et al. 2019) and other fish species, whereas telemetry focusing on small juvenile fish is less common (but see Wagner and Wahl 2011; Berejikian et al. 2016; Thompson et al. 2016). Telemetry has not been conducted on fingerling Walleye; thus, little is known about their poststocking survival and behavior, which are likely to vary among waterbodies due to differences in available habitat and community assemblages (Olson et al. 2000; Hoxmeier et al. 2006). Our objective was to use radiotelemetry to evaluate poststocking daily survival, depth use, dispersal, and home range size of fingerling Walleye (>200 mm TL) in three Iowa, USA, lakes.

METHODS

Study systems.— Big Creek Lake is 329-ha reservoir located in Polk County, Iowa, with a large (~20,000-ha) watershed that consists primarily of agricultural land (Figure 1). Big Creek Lake has a mean depth of 5.9 m, a maximum depth of 16.3 m, and water conductivity of 435 ± 36 μS/cm (mean ± SE). The lake is mostly devoid of emergent natural coarse woody habitat, but the Iowa Department of Natural Resources (Iowa DNR) placed more than 45 brush piles throughout the lake as fish habitat between 2007 and 2010. Big Creek Lake contains coontail *Ceratophyllum demersum*, sago pondweed *Potamogeton pectinatus*, and nonnative curly leaf pondweed *Potamogeton crispus* at low densities.

Brushy Creek Lake is a 280-ha reservoir located in Webster County, approximately 65 km north of Big Creek Lake (Figure 1). Completed in 1998, Brushy Creek Lake has a watershed that is comparable in size (~21,000 ha) and land use practices to those of Big Creek Lake. Brushy Creek Lake has a mean depth of 8.8 m, a maximum depth of 22.9 m, and water conductivity of 514 ± 32 μS/cm (mean ± SE), and a large amount of coarse woody habitat is present throughout the lake. A variety of aquatic vegetation is found in greater abundance at Brushy Creek Lake than at Big Creek Lake; species present include longleaf pondweed *Potamogeton nodosus*, coontail, common duckweed *Lemna minor*, sago pondweed, southern naiad *Najas guadalupensis*, watermeal *Wolffia* spp., two-leaf watermilfoil *Myriophyllum heterophyllum*, water stargrass *Heteranthera dubia*, brittle naiad *N. minor*, and curly leaf pondweed.

East Okoboji Lake is located in Dickinson County, 140 km northwest of Brushy Creek Lake (Figure 1). East Okoboji Lake is a long, narrow, and shallow eutrophic natural lake (743 ha) with a 32,050-ha watershed that consists primarily of agriculture. The lake's basin slopes gradually and has a mean depth of 3.2 m, a maximum depth of 6.7 m, and water conductivity of 377 ± 18 μS/cm (mean ± SE). Submersed aquatic vegetation is also abundant in East Okoboji Lake and is primarily composed of wild celery *Vallisneria americana*, flat-stem pondweed *Potamogeton zosteriformis*, curly leaf pondweed, bushy pondweed *Najas flexilis*, clasping-leaf pondweed *Potamogeton richardsonii*, and coontail. The upper two basins of East Okoboji Lake are dominated by curly leaf pondweed from late fall to early summer.

Piscivore assemblages in all three systems include Largemouth Bass *Micropterus salmoides*, Muskellunge *Esox masquinongy*, and adult Walleye. Northern Pike *Esox lucius* are present in East Okoboji Lake and Smallmouth Bass *Micropterus dolomieu* are also present in East Okoboji and Big Creek lakes but neither are present in Brushy Creek.

Fish tagging.— Large fingerling Walleye (hereafter referred to as Walleye; mean TL ± SE = 235.2 ± 2.3 mm; n = 15 per lake [45 fish total]; Table 1) were implanted with radio tags (Advanced Telemetry Systems [ATS] Model

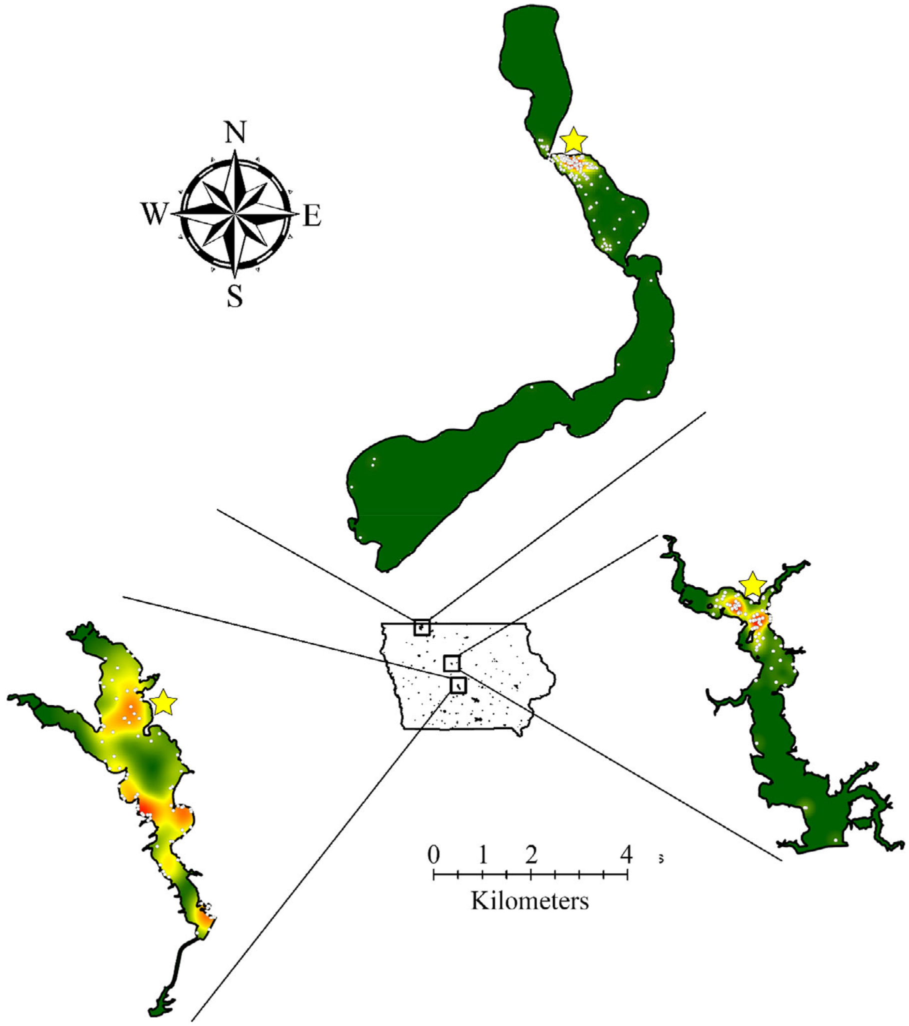

FIGURE 1. Locations and outlines of Big Creek (left), Brushy Creek (right), and East Okoboji (top) lakes, Iowa. Stars denote the stocking location at each lake. White circles in each lake represent known fish locations determined during tracking events. Interpolated color scale denotes limited-use areas (dark green) to high-use areas (red) based on the kernel density tool in the Spatial Analyst extension of ArcMap version 10.3.1.

F1540, 2 g in water, 240-d battery life; ATS, Isanti, Minnesota) at Rathbun Fish Hatchery, Moravia, Iowa. Average size of Walleye implanted with radio tags was similar across systems (mean TL ± SE, Big Creek Lake: 237.5 ± 4.0 mm; Brushy Creek Lake: 236.1 ± 4.0 mm; East Okoboji Lake: 233.5 ± 4.2 mm). Prior to each surgery, transmitters and surgical tools were disinfected in a 4% chlorhexidine scrub and rinsed with distilled water (Harms 2005). Electroanesthesia (Maxtens 1000 TENS unit; Bio-Protech, Chino, California) was used to immobilize fish during surgery. Fish were measured (TL, mm) and weighed (g) before being exposed to pulsed direct current. Electrical intensity was increased slowly until fish were immobilized, after which iodine ointment was applied along the linea alba before an incision was made anterior to the pelvic girdle (Wagner et al. 2011). The initial incision was made using a small scalpel, and iris scissors were used to enlarge the incision until the transmitter could be admitted into the body cavity (Wagner et al. 2011). After tag insertion, the whip antenna was inserted into a 16-gauge hypodermic needle, which was used to create an exit hole through the body wall anterior to the anus. Size 4/0 Maxon sutures (Medtronic, Inc., Dublin) were used to close the incision via an interrupted cruciate suture, and an additional single interrupted suture was used if needed (Deters et al. 2012). Walleye were then returned to the raceway and held for 16–20 d prior to stocking. No mortalities were observed at the hatchery, and no signs of infection were present near the incision site on each fish prior to stocking.

Transportation.— Walleye were transported to Big Creek Lake (169 km from Rathbun Fish Hatchery) on October 26, 2017 (lake temperature = 13.2°C); Brushy Creek Lake (275 km from the hatchery) on October 27,

TABLE 1. Summary information for fingerling Walleye that were radio-tagged and released into Big Creek, Brushy Creek, and East Okoboji lakes, Iowa, during fall 2017. “Day poststocking of last known location” refers to the last day that each fish was located and verified to be alive. “Fate by November 20, 2017” indicates whether Walleye were known to be alive, dead, or not located (unknown) prior to ice-up, whereas “Fate by March 15, 2018” indicates the fate of Walleye after ice-off.

Lake	Radio tag frequency (MHz)	TL (mm)	Weight (g)	Total locations	Day poststocking of last known location	Fate by Nov 20, 2017	Fate by Mar 15, 2018
Big Creek	0.570	241	120	11	25	Alive	Unknown
	0.591	219	80	10	25	Alive	Unknown
	0.610	240	123	10	21	Alive	Alive
	0.631	225	86	0	0	Unknown	Unknown
	0.650	250	130	14	217	Alive	Alive
	0.710	260	151	8	25	Alive	Unknown
	0.729	220	78	6	217	Alive	Alive
	0.754	221	88	5	99	Alive	Unknown
	0.771	259	169	13	190	Alive	Alive
	0.791	224	86	4	7	Unknown	Unknown
	0.851	238	98	8	173	Alive	Alive
	0.870	236	112	0	0	Unknown	Unknown
	0.891	265	160	10	195	Alive	Alive
	0.910	223	97	5	146	Alive	Unknown
	0.931	241	135	9	195	Alive	Alive
Brushy Creek	0.193	215	78	1	2	Unknown	Unknown
	0.210	240	114	11	75	Alive	Unknown
	0.232	248	133	2	7	Unknown	Unknown
	0.250	221	86	6	103	Alive	Unknown
	0.271	251	138	10	75	Alive	Unknown
	0.391	215	81	14	42	Alive	Unknown
	0.408	246	132	5	118	Alive	Unknown
	0.431	242	127	5	118	Alive	Unknown
	0.450	210	72	8	181	Alive	Alive
	0.470	265	136	4	6	Unknown	Unknown
	0.671	238	124	7	89	Alive	Unknown
	0.691	236	115	6	118	Alive	Unknown
	0.811	244	133	7	210	Alive	Alive
	0.831	226	90	2	1	Unknown	Unknown
	0.950	245	114	5	5	Unknown	Unknown
East Okoboji	0.072	221	79	21	135	Alive	Dead
	0.091	222	92	27	135	Alive	Alive
	0.110	241	106	26	184	Alive	Alive
	0.131	212	77	4	4	Dead	Dead
	0.151	251	138	26	184	Alive	Alive
	0.171	220	84	21	71	Alive	Dead
	0.291	264	155	24	135	Alive	Alive
	0.311	243	126	26	184	Alive	Alive
	0.331	229	105	24	123	Alive	Unknown
	0.350	230	98	19	93	Alive	Dead
	0.370	250	138	26	184	Alive	Alive
	0.490	209	73	18	135	Alive	Unknown
	0.511	245	133	11	18	Dead	Dead
	0.531	219	84	19	184	Alive	Dead
	0.550	246	131	29	135	Alive	Alive

2017 (lake temperature = 11.4°C); and East Okoboji Lake (480 km from the hatchery) on October 30, 2017 (lake temperature = 4.7°C). Walleye were unfed during the 48 h prior to transport to decrease waste (e.g., ammonia and carbon dioxide) during transportation (Robb 2008). The transportation truck had three 1,260-L compartments, all of which were equipped with ram-air ventilation and supplemental oxygen (0.2–0.4 L/min, with a maintained tank pressure at 276 kPa). Approximately 500 Walleye (mean ± SE = 60.7 ± 0.3 kg) were transported in each tank during each event, and radio-tagged Walleye were intermixed in the transportation truck with untagged conspecifics. Upon arriving to each system, a large hose was used to move Walleye from the truck to the lake and all Walleye were stocked from shore at a single location.

Radiotelemetry.— Radiotelemetry began on the evening of stocking and was conducted nightly for 1 week poststocking. During the second week poststocking, telemetry was conducted at least every other evening, after which fish were tracked on a weekly basis until lakes were ice covered (13 total tracking events between stocking and ice-on). Tracking typically commenced at dusk and continued until all fish had been located or all of the lake had been searched. We also periodically tracked terrestrial areas within a 1,600-m buffer around the lake to search for radio-tagged Walleye that may have been consumed by terrestrial or avian predators, but no tags were located on shore during any tracking event. After ice-up on each lake (December 2, 2017, at East Okoboji Lake; December 6, 2017, at Big Creek Lake; and December 8, 2017, at Brushy Creek Lake), Walleye were tracked bi-weekly on foot during safe ice and weather conditions (3–10 under-ice tracking events per lake). Walleye were tracked from fall 2017 until May 22, 2018, at East Okoboji Lake; May 25, 2018, at Brushy Creek Lake; and May 31, 2018, at Big Creek Lake, or approximately 240 d posttagging, corresponding to the maximum battery life of the radio tags.

Tracking was conducted using a three-element, folding Yagi radio antenna connected to an ATS Model R4000 receiver. During each tracking session, the receiver was set to scan at maximum volume and gain while the perimeter of the lake was slowly searched until a fish was detected. Upon detection of a fish, it was approached and the gain was gradually reduced until the signal was barely noticeable at the highest volume setting. Fish location was recorded in Universal Transverse Mercator coordinates when the receiver gain was at the lowest achievable setting and the signal strength was equal in all directions. When no movement was detected for a given fish over three or more consecutive tracking occasions and the radio tag would not move when the area was disturbed, the fish was considered dead and data were reviewed to determine when the fish was last located alive.

Survival analysis.— Apparent daily survival (φ) and detection probability (p) of radio-tagged Walleye were estimated using daily live encounter histories in Program MARK (White and Burnham 1999) using the live-capture Cormack–Jolly–Seber (CJS) open-population model to generate maximum-likelihood estimates of apparent survival (φ_j = conditional probability of surviving interval j given that the individual is alive and available for recapture during the interval) while accounting for imperfect detection of tagged fish. The CJS model assumes that (1) tagged individuals are representative of the population for which inferences are made; (2) the number of tagged individuals is known; (3) tagging does not affect survival; (4) releases and recaptures are made within brief time periods relative to the time between tagging; (5) recapture does not affect subsequent survival or recapture; (6) fates of individuals within and among cohorts are independent; and (7) individuals in a cohort have the same survival and recapture probability for each time interval (Burnham et al. 1987).

We developed a set of a priori hypotheses to evaluate factors that may influence survival and detection of Walleye. Parameters that may affect Walleye survival or detection probability include variation among lakes and seasons (fall: stocking through ice-up; winter: ice-up through ice-off; spring: after ice-off), a linear trend (T) in survival with time since stocking (i.e., survival either increases or decreases with time poststocking), and Walleye TL at stocking. Survival of stocked fish may also vary randomly as a function of time since stocking (t) or survival may be lower for a period of days since stocking (2, 5, 10, 20, or 30 d were evaluated) as the stocked fish acclimate, after which survival increases.

Due to a large number of possible model structures for survival and detection parameters, running every possible model combination was infeasible. Instead, we ran a set of candidate models whereby the model complexity within survival (variation among lakes and days) was used in all models while the effects of lake and days since stocking on detection probability were evaluated. After evaluating model structures of interest for detection probability, the most supported model structure for detection was retained and held constant when evaluating the various survival model combinations. Competing hypotheses were stated in model form in Program MARK using the logit link function and were compared using Akaike's information criterion corrected for small sample size (AIC_c; Burnham and Anderson 1998). The median $\hat{c}$ test was used to evaluate data overdispersion, and $\hat{c}$ was adjusted to 3.5. Thus, the quasi-likelihood AIC_c ($QAIC_c$) was used to compare models instead of AIC_c. The $QAIC_c$ difference ($\Delta QAIC_c$) was calculated as the $QAIC_c$ of the model with the smallest $QAIC_c$ value minus the $QAIC_c$ of a given model. Akaike weights (w_i) were also calculated to address potential uncertainty concerning the selection of the top model (Burnham and Anderson 1998).

Walleye depth use, dispersal, and home range analyses.— Walleye depth use, dispersal, and home range size were determined during 13 tracking events that occurred between stocking and ice-up (25 d poststocking). The period from stocking through ice-up was a critical period to evaluate poststocking behavior as Walleye acclimated to each lake. Although tracking also occurred during ice cover, infrequent tracking and low detections limited the number of observations during this period; therefore, those observations were not included for behavioral analyses.

Exact depth of individual Walleye at each observed location could not be determined. Instead, the maximum water depth at each Walleye location (0.1 m; hereafter referred to as depth use) was recorded and analyzed. Walleye dispersal from the stocking location (m) on each tracking event was calculated as the minimum straight-line, in-water distance between the stocking site and the fish's location. Minimum convex polygon (MCP) methods were used to estimate Walleye home range size. Walleye locations were plotted in ArcGIS, and 90% MCP home ranges were generated using Home Range Tools for ArcGIS 10 (version 2.0.20; Rodgers et al. 2015). The 90% MCP was used because it removes outliers that can considerably influence home range estimates (White and Garrott 1990). Home ranges were only estimated for Walleye that were located during at least 5 of the 13 tracking events from stocking until ice-up.

Depth use and dispersal were log transformed to normalize variance in the data and were analyzed using repeated-measures ANOVA (with individual fish as the repeated variable) with a first-order autoregressive covariance structure to evaluate the effects of lake, days poststocking, and the lake × days poststocking interaction (Wagner and Wahl 2011). An effect of lake would indicate differences in Walleye behavior among systems, an effect of days poststocking would indicate changes in Walleye behavior through time, and a lake × days poststocking interaction effect would indicate that changes in Walleye behavior among days poststocking vary among lakes. Individual fish were treated as subjects, with days poststocking specified as the repeated factor. If differences in the main effects or the interaction were detected, least significant difference means separation tests were used to determine where differences existed through time within a lake. Home range size was also log transformed and compared among lakes by using an ANOVA. All statistical analyses were conducted in the Statistical Analysis System (SAS Institute, Cary, North Carolina) using the MIXED procedure, and significance was assessed at $\alpha = 0.05$.

RESULTS

Survival

Walleye were tracked from October 26, 2017, to May 30, 2018. There was a total of 527 Walleye detections: 113 at Big Creek Lake, 93 at Brushy Creek Lake, and 321 at East Okoboji Lake (Table 1). Walleye were located, on average, through 102 d poststocking (minimum = 0 d, maximum = 217 d) across all three lakes. Only two Walleye at East Okoboji Lake were confirmed mortalities by November 20, 2017 (ice-up), whereas an additional four Walleye were confirmed dead by May 30, 2018 (Table 1). Mean TL of known Walleye mortalities (mean ± SE = 224 ± 5 mm) was smaller than the mean TL of those that survived or whose fate was unknown (237 ± 2 mm; $t = 2.31$, $P = 0.04$). Of the six known mortalities, three were believed to have occurred due to predation by fish (e.g., a potential predator was observed departing the area as the signal also diminished), whereas the cause of mortality could not be determined for the other three Walleye. No Walleye mortalities were confirmed at Big Creek Lake or Brushy Creek Lake, but the fates of three Walleye at Big Creek Lake and five Walleye at Brushy Creek Lake were unknown by November 20, 2017, approximately 3 weeks poststocking. By ice-off in mid-March, the number of Walleye with unknown fates had increased to 8 at Big Creek Lake and 13 at Brushy Creek Lake.

Overall, 27 models were evaluated to compare different effects on Walleye poststocking apparent survival and detection probability (Table 2). Six models had $\Delta QAIC_c$ values less than 3.0 and w_i greater than 0.10, indicating various levels of support in explaining apparent survival and detection probability. Models that were ranked 7 or greater had substantially larger $\Delta QAIC_c$ values and smaller w_i values, indicating little support. The most supported model indicated that Walleye detection probability varied among lakes and had a declining trend through time (Table 2; Figure 2). Other models with only lake, time (t), trend (T), and constant (.) effects were evaluated but received no support ($\Delta QAIC_c > 90$). Walleye detection probability was higher in East Okoboji Lake than in Brushy Creek Lake (slope $\beta = 1.96$; 95% CI = 1.51–2.42) and Big Creek Lake ($\beta = 1.74$; 95% CI = 1.31–2.16), but Walleye in Brushy Creek and Big Creek lakes had similar detection probabilities ($\beta = -0.23$; 95% CI = −0.64 to 0.19). Walleye detection probability was 0.90 in East Okoboji Lake, 0.56 in Brushy Creek Lake, and 0.62 in Big Creek Lake on the day of stocking and declined in all three lakes through time ($\beta = -0.04$; 95% CI = −0.05 to −0.03; Figure 2).

Walleye survival was best explained with a linear trend (T) on days since stocking (Table 2). Mean Walleye daily survival was as low as 0.964 on the day of stocking (day 1) but increased to 0.999 by 24 d poststocking ($\beta = 0.14$; 95% CI = 0.04–0.25; Figure 3). Cumulative survival indicated that most mortality occurred within the first 20 d, and cumulative survival was 0.76 (95% CI = 0.44–0.89) at 210 d poststocking. There was some support ($\Delta QAIC_c$

TABLE 2. Cormack–Jolly–Seber models used to estimate apparent daily survival (φ) and detection probability (p) of fingerling Walleye stocked into East Okoboji (EOkob), Brushy Creek (Brush), and Big Creek (Big) lakes, Iowa, during fall 2017. Effects included variation among lakes, daily variation (t), a trend in survival since time at stocking (T), season (fall, winter, or spring), and cohort mean length at stocking ($QAIC_c$ = quasi-likelihood Akaike's information criterion corrected for small sample size; $\Delta QAIC_c = QAIC_c$ difference; w_i = Akaike weight; K = number of parameters; QDeviance = [−2·{log-likelihood of the model}] − [−2·{log-likelihood of the saturated model}], where the saturated model has the same number of parameters and df).

Model	$QAIC_c$	$\Delta QAIC_c$	w_i	Model likelihood	K	QDeviance
φ(T), p(Lake + T)	2,699.05	0.00	0.29	1.00	6	2,686.90
φ([EOkob and Big versus Brush] + T), p(Lake + T)	2,700.98	1.93	0.11	0.38	7	2,686.78
φ(T + Length), p(Lake + T)	2,700.99	1.93	0.11	0.38	7	2,686.78
φ([EOkob and Brush versus Big] + T), p(Lake + T)	2,701.05	1.99	0.11	0.37	7	2,686.84
φ([EOkob versus Brush and Big] + T), p(Lake + T)	2,701.09	2.03	0.11	0.36	7	2,686.88
φ(T + Fall Length), p(Lake + T)	2,701.10	2.05	0.11	0.36	7	2,686.89
φ([EOkob and Big versus Brush] + T + Length), p(Lake + T)	2,702.94	3.88	0.04	0.14	8	2,686.67
φ(Lake + T), p(Lake + T)	2,703.04	3.98	0.04	0.14	8	2,686.78
φ([EOkob versus Brush versus Big] + T), p(Lake + T)	2,703.04	3.98	0.04	0.14	8	2,686.78
φ(Lake + T), p(Lake × T)	2,705.10	6.05	0.01	0.05	9	2,686.78
φ(Length), p(Lake + T)	2,705.18	6.13	0.01	0.05	6	2,693.03
φ(Lake + Season), p(Lake + T)	2,707.06	8.00	0.01	0.02	9	2,688.73
φ(Lake × Season), p(Lake + T)	2,707.06	8.00	0.01	0.02	9	2,688.73
φ([EOkob and Big versus Brush] + Length), p(Lake + T)	2,707.24	8.18	0.00	0.02	7	2,693.03
φ(Lake + Length), p(Lake + T)	2,709.28	10.23	0.00	0.01	8	2,693.02
φ(Lake × T), p(Lake)	2,727.66	28.61	0.00	0.00	7	2,713.46
φ(Lake × t), p(Lake × t)	3,533.07	834.02	0.00	0.00	248	2,634.78
φ(Lake × Day2), p(Lake)	15,418.88	12,719.82	0.00	0.00	9	15,400.55
φ(Lake × Day2), p(Lake × T)	15,422.20	12,723.14	0.00	0.00	11	15,399.71
φ(Lake × Day2 + Length), p(Lake × T)	15,423.09	12,724.04	0.00	0.00	12	15,398.52
φ([EOkob and Big versus Brush] × Day2), p(Lake × t)	15,577.01	12,877.96	0.00	0.00	80	15,389.73
φ(Lake × Day2), p(Lake × t)	15,582.01	12,882.96	0.00	0.00	82	15,389.23
φ(Lake × Day5), p(Lake × t)	15,606.06	12,907.00	0.00	0.00	91	15,387.97
φ(Lake × Day10), p(Lake × t)	15,649.70	12,950.65	0.00	0.00	106	15,387.18
φ(Lake × Day20), p(Lake × t)	15,748.12	13,049.06	0.00	0.00	136	15,387.18
φ(Lake × Day30), p(Lake × t)	15,861.71	13,162.66	0.00	0.00	166	15,387.18

< 2.0) that survival was similar in East Okoboji and Big Creek lakes but different in Brushy Creek Lake (Table 2; model 2), similar in East Okoboji and Brushy Creek lakes but different in Big Creek Lake (model 4), and similar in Brushy Creek and Big Creek lakes but different in East Okoboji Lake (model 5). There was also some evidence that Walleye survival was affected by length at stocking (model 3); Walleye apparent survival tended to increase with length at stocking each day (Figure 4), but the slope of this relationship did not differ from 0 ($\beta = 0.01$; 95% CI = −0.03 to 0.06).

Walleye Depth Use, Dispersal, and Home Range

Walleye depth use ranged from 0.3 to 19.3 m (mean = 2.5 m) and varied among lakes ($F_{2,\ 274} = 122.34$, $P < 0.0001$) but was similar among days poststocking ($F_{12,\ 274} = 1.31$, $P = 0.21$), and the lake × days poststocking interaction effect was not significant ($F_{24,\ 274} = 1.17$, $P = 0.27$). Walleye in Brushy Creek Lake used deeper water (mean ± SE = 5.1 ± 0.2 m) than those in Big Creek Lake (3.3 ± 0.2 m; $t = -7.23$, $P < 0.0001$) or East Okoboji Lake (1.7 ± 0.1 m; $t = 34.74$, $P < 0.0001$). Walleye in Big Creek Lake also used deeper water than those in East Okoboji Lake ($t = 7.37$, $P < 0.0001$).

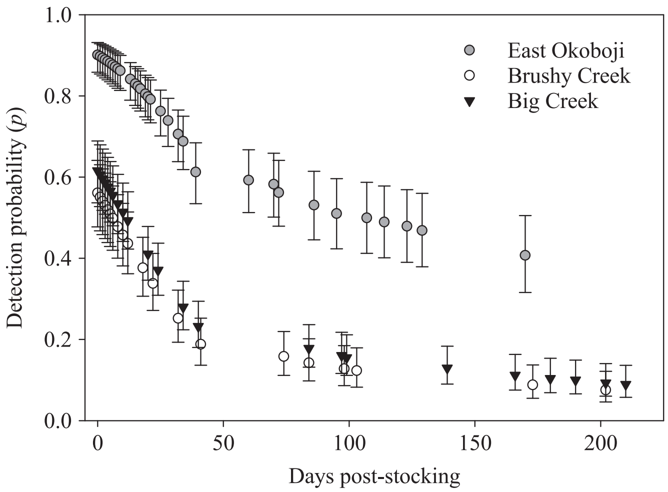

FIGURE 2. Detection probability (p; ±95% CI) in relation to days poststocking for large fingerling Walleye in East Okoboji Lake (gray shaded circles), Brushy Creek Lake (open circles), and Big Creek Lake (black triangles), Iowa.

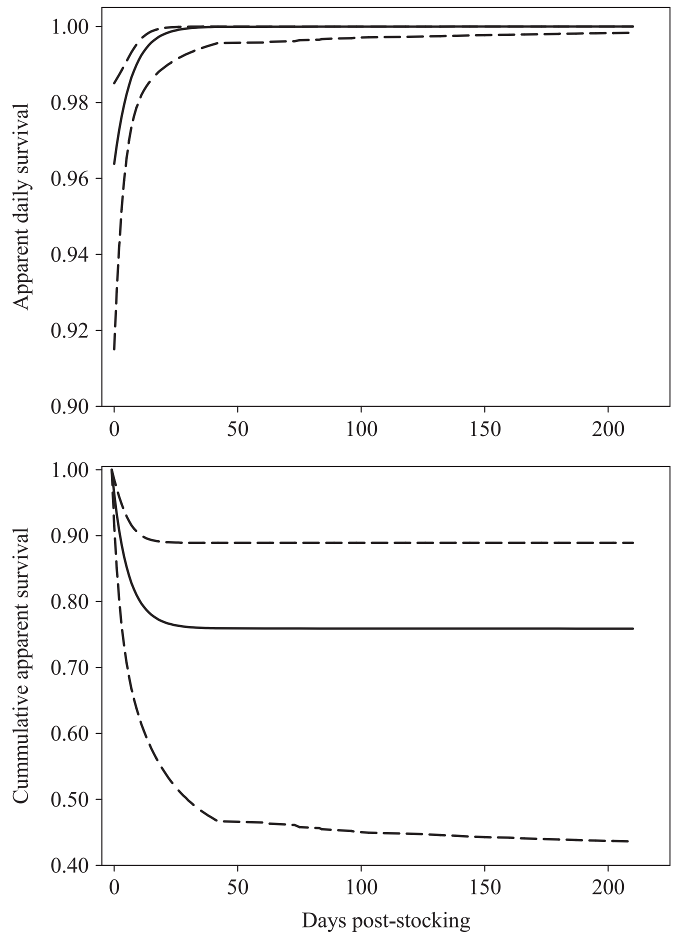

FIGURE 3. Apparent daily survival (top panel) and cumulative apparent survival (bottom panel) in relation to days poststocking for large fingerling Walleye in Big Creek, Brushy Creek, and East Okoboji lakes, Iowa, from October 2017 through May 2018 based on the most supported model. Solid line represents the mean, and dashed lines represent the 95% CI.

Walleye were located throughout each lake, but most fish locations were in proximity to the stocking location (Figure 1), with Walleye dispersal ranging from 34 to 8,364 m (mean = 912 m). Walleye dispersal varied among lakes ($F_{2,\ 40} = 12.02$, $P < 0.0001$) and among days poststocking ($F_{12,\ 240} = 3.88$, $P < 0.0001$), but the lake × days poststocking interaction was not significant ($F_{24,\ 240} = 1.21$, $P = 0.24$). Walleye dispersal was higher in Big Creek Lake (mean ± SE = 1,430 ± 272 m) than in Brushy Creek Lake (680 ± 267 m; $t = 4.00$, $P = 0.0003$) and East Okoboji Lake (935 ± 245 m; $t = 4.54$, $P < 0.0001$), but dispersal was similar between Brushy Creek and East Okoboji lakes ($t = 0.14$, $P = 0.89$). Walleye dispersed quickly after stocking, as fish were located more than 400 m from stocking locations on the day of stocking across all lakes (Figure 5). Walleye dispersal tended to increase with days poststocking for the first 13 d, after which dispersal did not vary through time (Figure 5). Finally, Walleye home range size from stocking through ice-up varied from 0.5 to 276.0 ha (mean = 38.3 ha). Similar to dispersal, Walleye home range size varied among lakes ($F_{2,\ 37} = 6.92$, $P = 0.003$) and was larger in Big Creek Lake than in Brushy Creek Lake or East Okoboji Lake, whereas the latter two lakes had similar Walleye home ranges (Figure 6).

DISCUSSION

Quantifying the poststocking survival and behavior of hatchery fish can provide valuable insights into the success of stocking programs and the potential for hatchery fish to contribute to the adult population. Our results indicate that fingerling Walleye survival was lower immediately after stocking but increased quickly within the first 20 d. There was some evidence indicating that Walleye length at stocking was associated with improved survival, but no differences in survival were detected among lakes.

Half of the known mortalities at East Okoboji Lake were attributed to predation by fish based on movement patterns prior to mortality, whereas the causes of the other mortalities could not be determined. We also observed more verified Walleye mortality in East Okoboji Lake ($n = 6$) compared to Brushy Creek Lake or Big Creek Lake, where no mortalities were confirmed but where the fates of 21 Walleye were unknown by May. However, models indicated that daily survival was high overall and did not support variation in Walleye survival rates among lakes. Walleye daily survival rates were lower immediately after stocking but increased dramatically with time poststocking, and high survival rates were observed thereafter. Mortality of juvenile Florida Largemouth Bass *Micropterus*

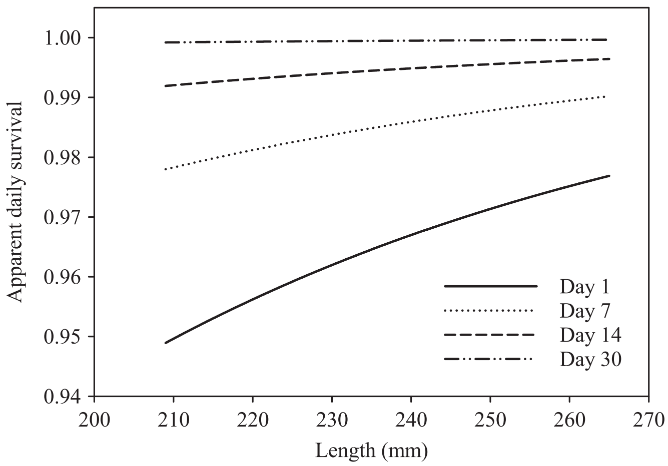

FIGURE 4. Apparent daily survival at 1, 7, 14, and 30 d poststocking in relation to TL for large fingerling Walleye in Big Creek, Brushy Creek, and East Okoboji lakes, Iowa, based on the third-ranked model.

salmoides floridanus also primarily occurred within the first 14 d poststocking in Florida and was attributed to predation (Thompson et al. 2016). Weekly survival rates of stocked Pallid Sturgeon *Scaphirhynchus albus* were also high (>98%; Eder et al. 2015), whereas only 26% of stocked Brown Trout *Salmo trutta* survived the first 32 d, with most mortality attributed to terrestrial predators (Aarestrup et al. 2005). Largemouth Bass predation on stocked Walleye occurred primarily within 3 d poststocking in Illinois reservoirs, and no predation was observed after 14 d (Freedman et al. 2012). The highest predation rates on stocked fish generally occur within 30 d of stocking (Wahl and Stein 1989; Santucci and Wahl 1993; Buckmeier et al. 2005), although predation on Walleye smaller than 100 mm may also be low during this period in some instances (Hoxmeier et al. 2006). Our data do not allow us to directly assess predation as the cause of mortality in this study, but previous research, observations during tracking events, and predator diet analyses on East Okoboji Lake (E. E. Ball, unpublished data) suggest that predation may be an important factor affecting Walleye poststocking survival.

Predation rates on stocked fish should decrease with fish size, as individuals stocked at larger sizes are vulnerable to fewer predators (Diana and Wahl 2009). The mean TL of known mortalities was smaller than the mean TL of surviving Walleye, and there was some support for models in which Walleye survival increased with TL. Large Walleye (178–203 mm) also had higher survival and produced year-classes more consistently than smaller Walleye (26–51 mm; Kampa and Hatzenbeler 2009). Studies of size-specific predation on Walleye have had mixed results: predation is often higher on smaller fish (Santucci and Wahl 1993), but in other instances no effect of size on

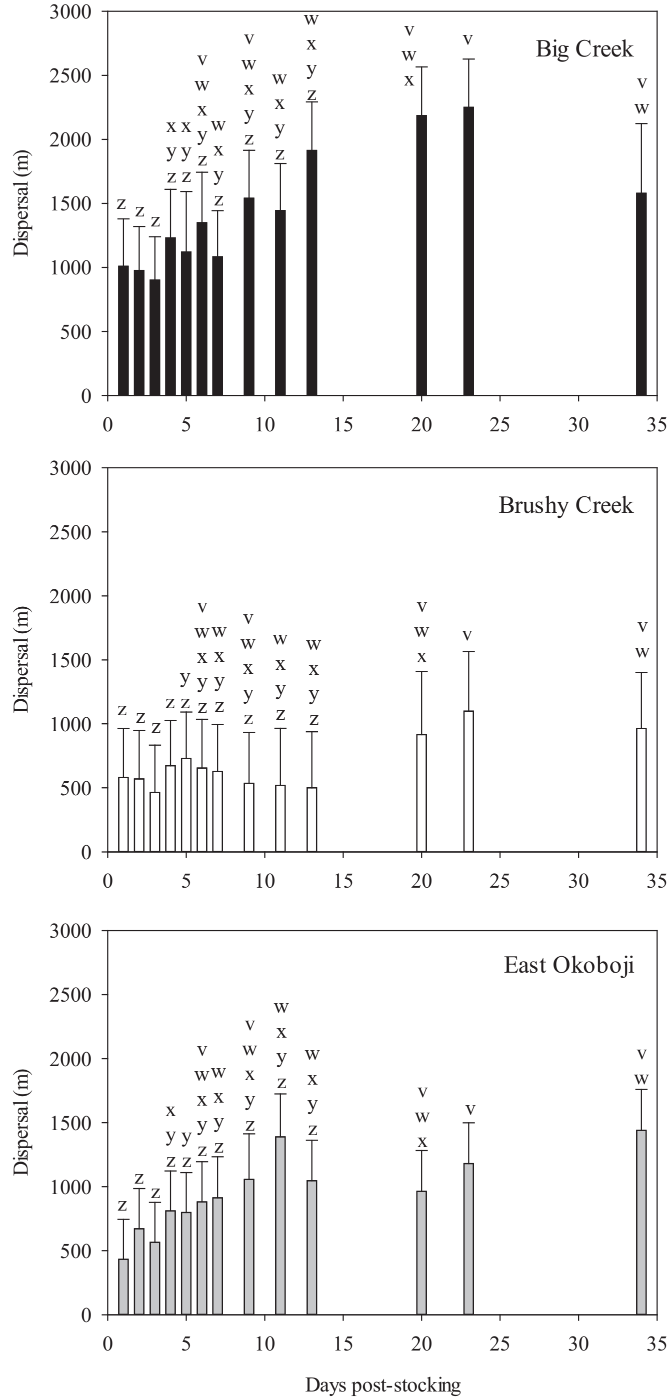

FIGURE 5. Dispersal (m; mean ± SE) of large fingerling Walleye from 0 to 34 d poststocking in Big Creek Lake (top panel), Brushy Creek Lake (middle panel), and East Okoboji Lake (bottom panel), Iowa, during fall 2017. For a given lake, different letters denote significant differences in dispersal among days.

predation has been observed (Jennings and Philipp 1992; Olson et al. 2000; Pratt and Fox 2003). Stocked Walleye in our study (mean TL = 235 mm) were larger than those

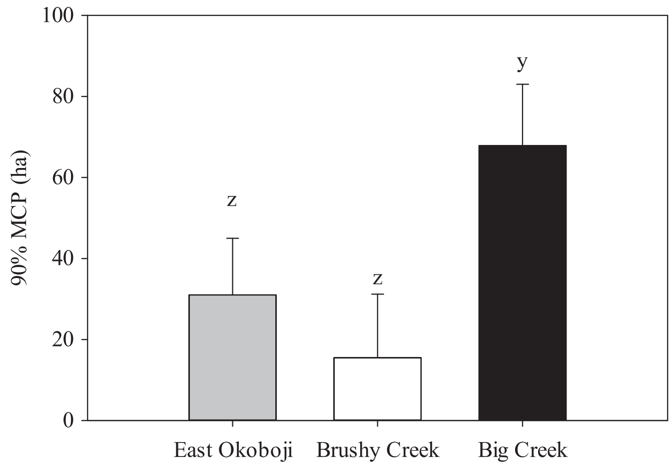

FIGURE 6. Ninety-percent minimum convex polygons (MCPs, ha; mean ± SE) of large fingerling Walleye in Big Creek, Brushy Creek, and East Okoboji lakes, Iowa, during fall 2017. Different letters denote significant differences in MCPs between lakes.

used in many other stocking evaluations (e.g., Santucci and Wahl 1993; Brooks et al. 2002; Hoxmeier et al. 2006; Kampa and Hatzenbeler 2009), which likely contributed to the higher overall survival rates. However, predation on large fingerling Walleye can still be an important factor affecting survival in some instances (Ball, unpublished data) and was believed to be an important source of mortality for fish in this study. Regardless of the mortality source, our results indicate that even small differences in Walleye size at stocking may affect survival rates.

Walleye depth use, dispersal, and home range size varied among lakes or among days poststocking, but interactions between these two parameters were not significant, indicating that poststocking behavior acclimation patterns were similar among lakes. Fish are generally stocked at a single location and can exhibit limited dispersal from stocking locations (Bolland et al. 2008). Walleye in this study dispersed quickly from the single stocking location at each lake but were only located a maximum of 2,250 m from the stocking location. Other telemetry studies have found that age-0 Florida Largemouth Bass dispersed over 700 m within 7 d poststocking in a Florida lake (Thompson et al. 2016), juvenile European Chub *Leuciscus cephalus* moved approximately 75 m/d after stocking (Bolland et al. 2008), and stocked Muskellunge dispersed a maximum of 67 km within 3 months poststocking in North Carolina rivers (Owensby et al. 2017). Other age-0 Walleye dispersed and were collected up to 8 km away from stocking locations in Green Bay, Lake Michigan (Zorn 2015). Our results also indicate that Walleye dispersal from stocking locations increased for approximately 2 weeks poststocking, after which fish did not disperse further. Limited dispersal of Walleye across a range of lake sizes and habitat types suggests that managers may consider multiple stocking locations throughout a lake to better distribute stocked fish while reducing the chances of density-dependent interactions and increasing the likelihood that some of them encounter conditions (e.g., habitat, prey, and predators) conducive for survival (Parsons and Pereira 1997; Lantry et al. 2011).

Habitat availability can affect fish dispersal, depth use, and home ranges among lakes, and variation in habitat (depth, coarse woody habitat, and vegetation) among the three lakes in this study likely also influenced Walleye behavior. For instance, juvenile Walleye had variable dispersal rates in three Minnesota lakes, where differences were hypothesized to be due to variable lake size and morphometry (Parsons and Pereira 1997), whereas juvenile Largemouth Bass exhibited increased movement rates, inhabited greater depths, and had larger home ranges in systems where vegetation or coarse woody habitat was actively removed or naturally present in low quantities (Sammons et al. 2003; Ahrenstorff et al. 2009). Walleye dispersal and home ranges in our study were largest in Big Creek Lake, which has limited submerged coarse woody habitat and submerged aquatic vegetation. In contrast, dispersal was lower and constant through time in Brushy Creek and East Okoboji lakes, both of which have an abundance of curly leaf pondweed that may have provided the necessary habitat for Walleye near stocking locations. Age-0 Walleye prefer areas of dense macrophyte cover in 2–5 m of water (Kerr et al. 1997), and low survival of stocked Walleye has also been attributed to a lack of suitable habitat (Perrin et al. 2003; Kerr 2007). Therefore, the addition of habitat near stocking locations may be an option for improving the survival of stocked fishes.

The use of telemetry can be a valuable tool for assessing survival and behavior of stocked fish but has associated limitations. Telemetry tags are substantially more expensive than passive tags, and typically fewer individuals can be tagged and tracked. Therefore, our estimates of Walleye survival and behavior are based on a relatively small sample size that we assume is representative of the population, but cumulative apparent survival could not be estimated precisely. Small sample size also likely affected our ability to detect differences in survival among lakes despite apparent differences in the number of known mortalities. Regardless of these limitations, an important advantage of telemetry is that it allows for higher detection probability and can provide data about fish survival and dispersal without altering behavior via capture. Conversely, fish with passive tags must be physically recaptured on multiple events, which is extremely difficult and labor intensive. Radiotelemetry is also limited by environmental conditions, where detection of tags becomes difficult in deeper depths. We observed that detection probability declined as Walleye dispersed after stocking and used deeper depths, potentially biasing depth use data to be shallower than the depths actually used by the fish and biasing dispersal to smaller distances. Telemetry is also limited by tag battery life. Although we used a conservative estimate of tag battery life as the final tracking date, we were unable to locate a large number of Walleye after ice-off, potentially due to premature failure of radio tag batteries, as has been reported in other studies (e.g., Thompson et al. 2016). Individual Walleye telemetry encounter histories were used to estimate apparent survival, which includes both mortality and emigration. If Walleye permanently moved to deeper waters where they could not be detected or if the batteries failed prematurely, then these fish would likely have been treated as mortalities in our CJS models and consequently the apparent survival estimates would have been biased downward. However, by spring 2018 the Walleye cumulative survival estimates were high (mean = 76%), suggesting that these potential biases were negligible. Whether these high survival estimates are common for stocked Walleye or whether favorable environmental conditions during stocking resulted in higher survival during fall 2017 is unknown. Additional information across multiple years and stocking events would help to determine annual variation in survival rates of stocked Walleye. Finally, important differences can exist in the behavior and survival of stocked versus wild fish due to domestication of hatchery fish (Olla et al. 1998; Thompson et al. 2016). Thus, future studies should examine the behavior and survival of stocked Walleye in comparison with their wild counterparts.

We have demonstrated the value of telemetry for providing important insights into poststocking survival and behavior of Walleye. Our results indicate that stocked fingerling Walleye experience high survival rates across a range of lakes. Assessment of the poststocking survival rates of hatchery fish is important for understanding the timing and sources of mortality that can result in recruitment success or failure. Most mortality occurred during the first 20 d of dispersal, and larger fish tended to survive better than smaller fish, suggesting that size is important for poststocking survival even in large fish and that managers should focus on identifying ways to improve survival during this period. Behaviors of stocked fish are also important to understand, as they can affect evaluations of predation, stocking population contribution, and angling success (Parsons and Pereira 1997). Our results provide insights into the poststocking fates of Walleye and indicate that behaviors vary across lakes, likely due in part to variation in habitat availability. Survival rates of fingerling Walleye were high overall but were initially lower post-stocking and increased through time. Cumulatively, our results on poststocking behavior and survival of Walleye can help to guide stocking decisions about where and how many fish should be stocked and provide foundational information that can be used in future evaluation of survival relative to stocking location and available habitat characteristics.

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