Transactions of the American Fisheries Society 140:31–36, 2011

ISSN: 0002-8487 print / 1548-8659 online
DOI: 10.1080/00028487.2011.545018

NOTE

Identifying Relationships between Catches of Spawning Condition Yellow Perch and Environmental Variables in the Western Basin of Lake Erie

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Abstract
Although the reproductive behavior of yellow perch *Perca flavescens* has been well documented in small systems, relatively little is known about the spawning preferences of yellow perch in large systems, such as the Laurentian Great Lakes. During 2006 and 2007, we compared the presence and abundance adult yellow perch during the spring spawning season with environmental variables in the western basin of Lake Erie. We also estimated the timing of yellow perch spawning by comparing the relative abundance of gravid and spent females collected in our trawls and then comparing the proportion of gravid females with environmental conditions at our sampling sites. Overall, the probability of catching adult yellow perch and the catch per unit effort increased with increasing bottom temperatures in the spring, whereas the probability of catching gravid females increased with increasing Secchi depth. However, the relationships between our catch metrics and environmental variables were not consistent across years, possibly as a result of the very strong 2003 year-class, which became first-year spawners in 2006. We also documented that yellow perch spawning occurred when bottom temperatures were between 11°C and 15°C in the western basin; these temperatures were reached on different dates in different parts of the basin and in different years. Thus, we suggest that management agencies consider basing the start of the commercial fishing season on prevailing bottom temperatures rather than using a set date across years and sites.

The reproductive behaviors of yellow perch *Perca flavescens* and the closely related Eurasian perch *P. fluviatilis* have been intensively studied. In North America, yellow perch spawning occurs annually during the spring or early summer as water temperatures approach 8–10°C (Keast 1968; Forney 1971), but considerable variation in peak spawning temperatures and spawning duration exists across the geographical range of this species (Hokanson 1977). For example, northern populations may initiate spawning behavior at lower temperatures and at a later date and may have a shorter duration of spawning than southern populations (Thorpe 1977). In small systems, female yellow perch attach egg skeins—a buoyant, gelatinous matrix in which the eggs are embedded—across vegetation and woody debris in shallow areas (Nelson and Walburg 1977; Thorpe 1977).

Although considerable research has been conducted to describe yellow perch spawning behavior and habitat selection in small lakes, relatively little is known about the spawning habitat of yellow perch in large systems, such as the Laurentian Great Lakes. Due to the large amount of wave energy generated along the shorelines of large systems (e.g., Lake Erie), the vegetated habitat typically used for spawning in small inland lakes is rare in large systems, particularly during the early spring. Goodyear et al. (1982) suggested that yellow perch spawning occurs along the entire southern shore of Lake Erie and that spawning areas are evenly dispersed from the mouth of the Niagara River (eastern basin) to the mouth of the Detroit River (western basin). However, the shallow-water habitats along this shoreline vary widely in substrate types, coastal geomorphology, and wave exposure, so spawning is unlikely to be evenly distributed along the shoreline. Previous studies have shown that yellow perch spawning in large systems does not occur randomly but is concentrated in areas of preferred depths and substrates (Thorpe 1977; Jones 1982; Robillard and Marsden 2001). For example, given the buoyancy of their eggs, yellow perch spawning in large systems that lack vegetation may prefer areas where eggs can be attached to stable substrates. Such spawning behavior has been observed in Lake Michigan, where catches of male yellow

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Received December 4, 2009; accepted October 6, 2010
Published online February 15, 2011

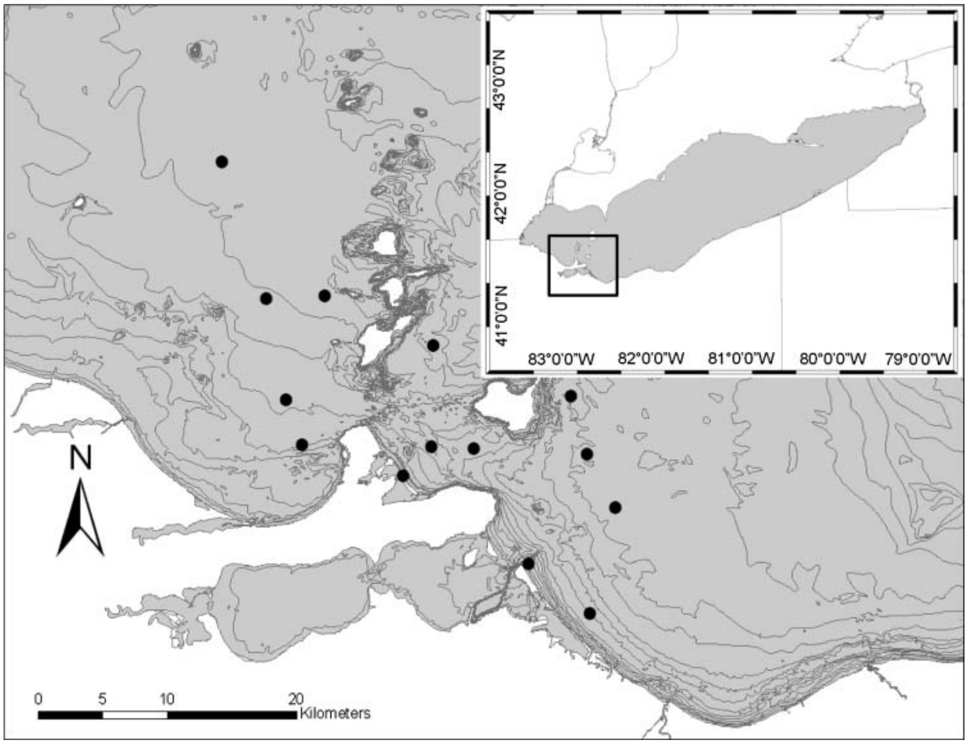

FIGURE 1. Map of the Bass Islands area of the western basin of Lake Erie, showing the locations of sites (black circles) where adult yellow perch were sampled during the 2006 and 2007 spawning seasons.

perch in spawning condition frequently occur at sites with cobble substrates (Robillard and Marsden 2001). The relationship between catches of yellow perch in spawning condition and physical habitat variables other than substrate type (e.g., depth, water transparency, and temperature) in large systems has not been widely studied.

The objectives of this study were to characterize the location of yellow perch spawning aggregations and the timing of yellow perch spawning in the western basin of Lake Erie. Specifically, we sought to determine whether (1) catches of adult yellow perch are related to physical habitat features (depth, water clarity, and water temperature) during the spawning season; (2) relationships between catches and physical habitat features are similar across geographic areas and across years; and (3) bottom temperatures can be used to predict the timing of yellow perch spawning events. If spawning adults aggregate in association with physical habitat features in a consistent way across space and time, we can use this information to infer spawning habitat selection by yellow perch. We used weekly bottom trawl catches of adult yellow perch during the spring spawning season to determine the relationship between catches of spawning yellow perch and habitat features of the western basin of Lake Erie.

METHODS

Adult yellow perch were sampled weekly during the spring spawning season (late March through May) in 2006 and 2007 at 14 sites clustered around the Bass Islands in the western basin of Lake Erie (Figure 1). Each year, sampling was initiated when surface water temperature reached approximately 4°C; sampling continued on a weekly basis for 7 weeks and concluded when water temperature reached 15°C. Based on the temperature criterion, sampling began 11 d earlier in 2006 (March 30) than in 2007 (April 11) due to differences in spring warming rates between years. At each site, yellow perch were sampled during a 10-min tow of an otter trawl with a 5.9-m footrope, 39-mm stretch mesh, and a 13-mm-mesh cod end. In total, 196 trawls were conducted over the course of the study, and all were conducted during daylight hours. When we were unable to run a complete 10-min trawl, such as when the trawl became snagged, we redeployed the trawl and attempted the trawl a second time. If the second trawl was unsuccessful but was run for at least 5 min, we multiplied the catch present in the reduced trawl to represent a completed 10-min trawl. This process was necessary for 5 ($<3\%$) of the 196 trawls in the study. All mature yellow perch were counted, and the sex and gamete condition of all fish were determined by expressing gametes or by dissection. Male yellow perch were classified as either immature (immature testes, or gametes were not expressed) or mature (gametes were expressed), whereas females were classified as immature (immature ovaries with no visible egg development), gravid (eggs were developed, but the female was not ovulating), ripe running (ovulating), or spent (postspawn). Depth, bottom temperature, and Secchi depth were also measured and recorded at each site prior to trawling.

From our trawls, we developed three yellow perch catch metrics for statistical analyses: the probability of catching adults, the catch per unit effort (CPUE), and the probability of catching gravid females. Because we were interested in the distributions of spawning adult yellow perch, all immature fish were excluded from the catch metrics. The probability of catch was calculated as the number of trawls that contained an adult yellow perch divided by the number of trawls conducted. Catch per unit effort was the number of mature yellow perch collected during the 10-min sampling interval. The probability of gravid females was calculated as the number of trawls that contained at least one gravid female divided by the number of trawls that caught adult yellow perch. The statistical analyses for probability of catch and gravid females were run using presence/absence data similar to a logistic regression.

For this project, the presence of mature females was of particular interest in our analyses. Because spawning behavior was not directly observed, yellow perch spawning site use and the timing of spawning were inferred by the presence of adults expressing gametes (Robillard and Marsden 2001). Yellow perch often spend the winter in deep water before moving to nearshore areas in the spring just prior to spawning (Thorpe 1977), and egg deposition typically lasts for 2–3 d (Tsai and Gibson 1971). Because movements to spawning grounds can cover large distances, we anticipated catching fish in various stages of spawning condition throughout the spring at many sites. Whereas spent females may be a considerable distance from spawning grounds, gravid and ripe-running females are more likely to be near their final spawning site. If catches of mature females are random with respect to environmental variables, we could conclude that our characterization of habitats has not captured the factors driving yellow perch spawning site use in large systems. However, if catches are more likely to occur under certain environmental conditions, yellow perch may be selecting spawning sites based on these specific environmental characteristics. In addition, the presence of gravid females was also used to infer the timing of yellow perch spawning in the western basin. For trawls that caught multiple mature females, we used the ratio of gravid females to ripe-running and spent females to determine the environmental conditions under which yellow perch were depositing eggs.

Data analyses.—We analyzed catches of adult yellow perch by using the GENMOD procedure in the Statistical Analysis System version 9.1.3 (SAS 2005). The dependent variables of interest in our statistical analyses were our catch metrics—namely, the probability of catching adults, the CPUE, and the probability of catching gravid females. The independent variables used to construct the models were year, depth, bottom temperature, and Secchi depth. Based on visual inspection of the data, catches of yellow perch appeared to differ across years. To help quantify this variation, we included interaction terms between all environmental variables and years. Because our sampling protocols included making repeated measurements at the same sites over multiple weeks within a year, we expected that catches would be correlated among sampling sites. To ensure that our statistical models accounted for the correlation among observations at sampling sites, we used a generalized estimating equations approach (Liang and Zegler 1986). An extension of generalized linear models, the generalized estimating equations method provides a semiparametric approach to analyzing nonnormal longitudinal data. The probability of catching adults and the probability of catching gravid females were modeled by use of binomial regression with a logit link function. Catch per unit effort was modeled using Poisson regression with a log link function to account for the nonnormal data structure. For all models, significance tests for independent variables were conducted with type III Wald chi-square statistics at a significance level of 0.05.

RESULTS

The probability of catching adult yellow perch was significantly influenced by several of the environmental variables measured at our sampling sites (Table 1). Overall, the probability of catching adults was significantly influenced by year, bottom temperature, and Secchi depth. The probability of catching adults was positively correlated with bottom temperature ($\beta = 680.78$, $\chi^2 = 26.84$, df $= 1{,}184$, $P < 0.0001$) and Secchi depth ($\beta = 20.97$, $\chi^2 = 5.63$, df $= 1{,}184$, $P = 0.02$). We also detected significant interactions between sampling year and bottom temperature ($\beta = -0.34$, $\chi^2 = 26.83$, df $= 1{,}184$, $P < 0.0001$) and between sampling year and Secchi depth ($\beta = -0.01$, $\chi^2 = 5.63$, df $= 1{,}184$, $P = 0.02$) in our trawl data series. Because the interaction between year and bottom temperature had the largest measured influence on the probability of catching adult yellow perch, we focus on this interaction separately. During 2006, the probability of catching adults was low when bottom temperatures were less than 9°C but increased as bottom temperature increased throughout the remainder of the spawning season (Figure 2). However, this pattern was not consistent across years; in 2007, the probability of catching adults was highest at very low

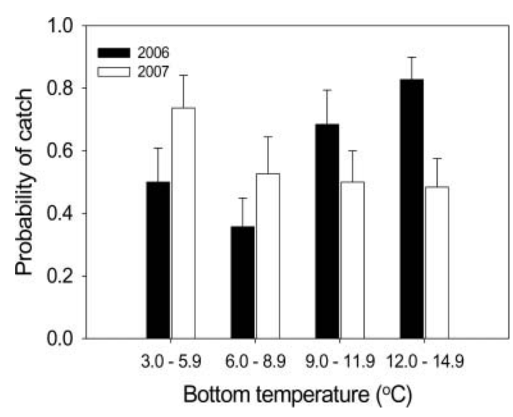

FIGURE 2. Histogram showing the relationship between bottom temperature and the probability of catching adult yellow perch in bottom trawls during the 2006 and 2007 spawning seasons.

TABLE 1. Environmental variables associated with the probability of catching adult yellow perch in bottom trawls in the western basin of Lake Erie. Probability of catch was modeled with binomial regression, and sample site was incorporated into the model as a random variable. Environmental variables were considered significant predictors of the catch probability if *P* was less than 0.05.

Parameter	Estimate	SE	χ^2	*P*
Intercept	−8408.36	1362.64		
Year	4.19	0.68	38.07	< 0.0001
Depth	11.98	55.07	0.05	0.83
Bottom temperature	680.78	131.41	26.84	< 0.0001
Secchi depth	20.97	8.84	5.63	0.02
Year depth	−0.01	0.03	0.05	0.83
Year bottom temperature	−0.34	0.07	26.83	< 0.0001
Year Secchi depth	−0.01	0.00	5.63	0.02

TABLE 3. Environmental variables associated with the probability of catching gravid female yellow perch in bottom trawls. Probability of catching gravid females was modeled with binomial regression, and sample site was incorporated into the model as a random variable. Environmental variables were considered significant predictors if *P* was less than 0.05.

Parameter	Estimate	SE	χ^2	*P*
Intercept	6, 148.07	3, 960.26		
Year	−3.07	1.97	2.41	0.12
Depth	−277.66	116.19	5.71	0.02
Bottom temperature	−54.76	275.12	0.04	0.84
Secchi depth	82.75	25.09	10.87	0.001
Year depth	0.14	0.06	5.72	0.02
Year bottom temperature	0.03	0.14	0.04	0.84
Year secchi depth	−0.04	0.01	10.88	0.001

bottom temperatures (<6°C) and then remained at intermediate levels throughout the remainder of the spawning season.

Adult yellow perch CPUE varied widely across sampling dates and years (mean CPUE = 7.7 adults/10-min tow; range = 1–53 adults/10-min tow). As is common with count data, many of the trawls conducted during the study did not catch adult yellow perch, resulting in a data set that contained many zeros. From the regression model, CPUE was significantly influenced by bottom temperature ($\beta = 483.77$, $\chi^2 = 22.07$, df = 1,184, $P < 0.0001$) and Secchi depth ($\beta = 24.78$, $\chi^2 = 13.34$, df = 1,184, $P < 0.001$) and by the interactions between these two independent variables and sampling year (year × bottom temperature: $\beta = –0.24$, $\chi^2 = 22.05$, df = 1,184, $P < 0.0001$; year × Secchi depth: $\beta = –0.01$, $\chi^2 = 13.34$, df = 1,184, $P < 0.001$; Table 2). As with the probability of catching adult yellow perch, the adult CPUE was positively related to bottom temperature and Secchi depth and was affected by the interactions between sampling year and bottom temperature and between sampling year and Secchi depth (Table 2). During both sampling years, CPUE of adult yellow perch was low when bottom temperatures were below 9°C. When bottom temperature increased above 9°C, CPUE increased approximately threefold in 2006, whereas it remained low throughout the spawning season in 2007 (Figure 3).

Adult yellow perch were collected in 110 (56%) of the 196 trawls conducted over the course of the study. In the logistic regression model, the proportion of captured females that were gravid was influenced only by Secchi depth ($\beta = 82.75$, $\chi^2 = 10.87$, df = 1,101, $P = 0.001$) and the interaction between Secchi depth and year ($\beta = –0.04$, $\chi^2 = 10.88$, df = 1,101, $P = 0.001$; Table 3). Overall, the proportion of gravid females was positively correlated with water transparency; however, the positive relationship between the proportion of gravid females and Secchi depth was not consistent across years. The proportion of gravid females increased with Secchi depth in 2006, but in 2007 the proportion was low across the entire range of measured water transparency values (Figure 4).

TABLE 2. Environmental variables associated with adult yellow perch CPUE in bottom trawls. Catch per unit effort was modeled with Poisson regression, and sample site was incorporated into the model as a random variable. Environmental variables were considered significant predictors of CPUE if *P* was less than 0.05.

Parameter	Estimate	SE	χ^2	*P*
Intercept	−5, 173.94	2, 254.11		
Year	2.58	1.12	5.27	0.02
Depth	4.90	49.31	0.01	0.92
Bottom temperature	483.77	102.98	22.07	< 0.0001
Secchi depth	24.78	6.79	13.34	< 0.001
Year depth	−0.00	0.02	0.01	0.92
Year bottom temperature	−0.24	0.05	22.05	< 0.0001
Year Secchi depth	−0.01	0.00	13.34	< 0.001

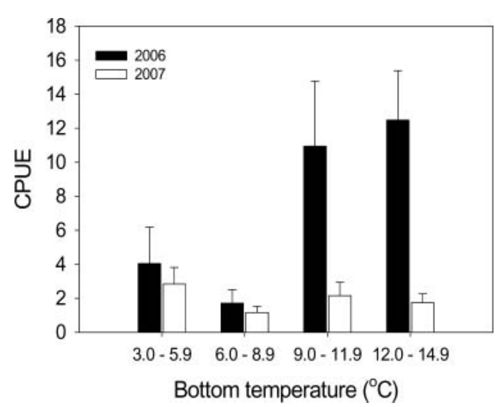

FIGURE 3. Histogram showing the relationship between bottom temperature and the adult yellow perch CPUE (adults/10-min tow) in bottom trawls during the 2006 and 2007 spawning seasons.

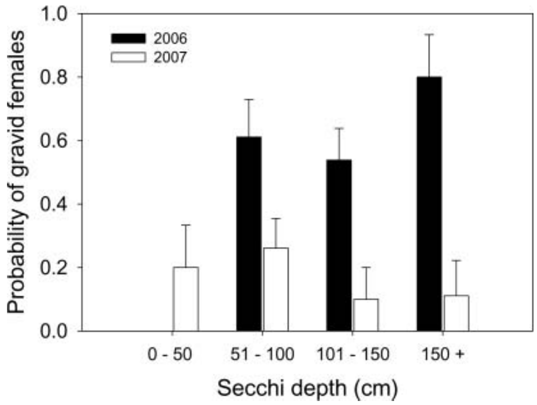

FIGURE 4. Histogram showing the relationship between Secchi depth and the probability of catching gravid female yellow perch in bottom trawls during the 2006 and 2007 spawning seasons.

Multiple adult females were captured in 66 (60%) of the 110 trawls that collected adult yellow perch over the duration of the study. Upon visual inspection of the data, there was an obvious and consistent relationship between the proportion of gravid females and bottom temperature (Figure 5). Early in the spring, when bottom temperatures were less than 10°C, all adult female yellow perch collected in the trawls were gravid. Later, as bottom temperature warmed to between 11°C and 15°C, we caught a mixture of flowing and spent females along with gravid females. With the exception of a single outlier, the relationship between the proportion of gravid females in the trawls and bottom temperature was consistent across years. Thus, we can infer that yellow perch spawn in the western basin of Lake Erie when bottom temperatures are between 11°C and 15°C.

DISCUSSION

One of our objectives was to relate catches of yellow perch during the spawning season to environmental variables in the western basin of Lake Erie. Overall, bottom temperature was positively related to both the presence of adult yellow perch and the number of adult yellow perch caught. Water temperature, like photoperiod, is one of the main environmental cues that initiate the final stages of gonad development and ovulation in yellow perch (Dabrowski et al. 1996). One plausible explanation for the positive relationship between catches of yellow perch and increasing water temperature is that adult yellow perch, which are dispersed throughout the fall and winter, form aggregations near spawning areas as water temperatures increase in the spring (Ferguson 1958).

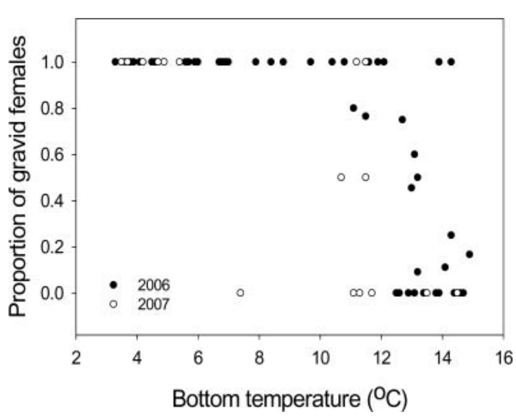

FIGURE 5. Proportion of gravid female yellow perch collected in bottom trawls plotted against bottom temperature during the 2006 and 2007 spawning seasons.

Secchi depth was another significant environmental predictor for catches of yellow perch. Throughout the study, water transparency was generally higher at deeper offshore sites than at shallower nearshore habitats. The presence of females in spawning condition at deep offshore sites throughout the spawning season suggests that these offshore habitats serve as staging areas and potentially as spawning areas for yellow perch. Surprisingly, we found no evidence for inshore movements of yellow perch during the spawning season in the western basin. Nearshore spawning migrations may be more pronounced in systems with deep offshore waters, such as the central and eastern basins of Lake Erie as well as the other Laurentian Great Lakes.

Bottom temperature and Secchi depth were positively related to catches of yellow perch in bottom trawls, but these relationships were not consistent across years. All yellow perch catch metrics were lower in 2007 than in 2006; fish also tended to be found more frequently in warm water during 2006 than during 2007. The 2006 spawning season was the first year in which large numbers of fish from the very successful 2003 year-class became mature; thus, spatial distributions observed in 2006 may reflect the distributions of dense aggregations of first-time spawners.

Although this study was not designed to directly observe yellow perch spawning activity, catches of females in spawning condition reveal that yellow perch in the western basin spawn during a brief time interval when bottom temperatures are between 11°C and 15°C. Across the species' geographic range, yellow perch spawning occurs between 4°C and 19°C. Thus, yellow perch in the western basin spawn at the high end of this temperature range but very near the optimal temperature for gamete viability (8–11°C; Hokanson 1977). Because water temperatures increase at different rates across the western basin, this spawning temperature interval will occur at different times depending on the location and depth of a spawning site. At our sample sites along the southern shoreline, shallow sites west of the Bass Islands were the fastest to warm in the spring, and deep sites off the eastern shore of Kelly's Island exhibited the slowest warming. Depending on weather patterns, the start of this temperature interval may differ among sites by up to 3 weeks in a given year, which would distribute yellow perch spawning activity temporally and spatially. From a population recruitment perspective, this protracted spawning behavior may increase the probability that spawning activity in some part of the western basin will coincide with appropriate environmental conditions for emerging larvae, thus maximizing the potential for reproductive success across the basin as a whole (Cushing 1969; Secor 2000). Such behavior also has important implications for the management of the yellow perch fishery in Lake Erie. Currently, the commercial fishing season for yellow perch in Lake Erie begins on May 1. From our data, water temperatures are typically above 15°C throughout most of the western basin by this date. However, bottom temperatures in the easternmost portion of the western basin warm more slowly, and yellow perch may not have an opportunity to spawn prior to the initiation of commercial fishing. Therefore, to protect yellow perch during spawning, we suggest that management agencies consider basing the start of the commercial fishing season on bottom temperatures instead of using a set date.

ACKNOWLEDGMENTS

We thank the personnel at the Sandusky Fisheries Research Unit of the Ohio Division of Wildlife for their assistance with this study. Roger Knight and Jeff Tyson in particular provided helpful comments during the initial stages of survey design. We also thank the many researchers at the Ohio State University Aquatic Ecology Laboratory and F. T. Stone Laboratory who provided technical help in the field. We greatly appreciate Richard Beamish and two anonymous reviewers for providing comments that improved the text of this manuscript. This research was funded by Federal Aid in Sport Fish Restoration Project F-69-P, which is administered jointly by the U.S. Fish and Wildlife Service and the Ohio Department of Wildlife, and by the Department of Evolution, Ecology, and Organismal Biology at Ohio State University.

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