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RESEARCH ARTICLE

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Occurrence, abundance and associations of Topeka shiners (*Notropis topeka*) in restored and unrestored oxbows in Iowa and Minnesota, USA

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Abstract

1. In the USA, the Topeka shiner (*Notropis topeka*) is a federally listed endangered species that has been in decline for decades. A key reason for the decline is the alteration of naturally flowing streams and associated oxbow habitats resulting from land-use changes. The focus of recent conservation efforts for Topeka shiners has been the restoration of oxbow habitats by removing sediment from natural oxbows until a groundwater connection is re-established. This restoration practice has become common in portions of Iowa and south-west Minnesota.
2. The goals of this study were to compare the occurrence and abundance of Topeka shiners in restored and unrestored oxbows and to determine the characteristics that influenced their presence in these systems.
3. In 2016–2017, 34 unrestored and 64 restored oxbows in the Boone, Beaver Creek, North Raccoon and Rock River basins in Iowa and Minnesota were sampled for their fish assemblages and abiotic features. Topeka shiners were present more often and with higher average relative abundances in restored oxbows.
4. Nonmetric multidimensional scaling ordinations indicated that fish assemblages found in oxbows where Topeka shiners were present were less variable than assemblages found at oxbows where they were absent, but that abiotic characteristics were similar between oxbow types.
5. Logistic regression models suggested that the presence of Topeka shiners in oxbows was positively associated with species richness, brassy minnow (*Hybognathus hankinsoni*) catch per unit effort (no. fish/100 m^2; CPUE), orangespotted sunfish (*Lepomis humilis*) CPUE, dissolved oxygen and turbidity, and negatively associated with oxbow wetted length. These results highlight the use of restored oxbows by Topeka shiners while also providing new information to help guide restoration and conservation efforts.

KEYWORDS

endangered species, habitat, *Notropis topeka*, oxbows, restoration, Topeka shiner

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1 | INTRODUCTION

Land-use changes since European settlement have contributed to profound landscape changes and altered habitats throughout the USA (Bailey, Ober, Sovie, & Mccleery, 2017; Foster, Motzkin, Bernardos, & Cardoza, 2002; Juracek, Eng, Carlisle, & Wolock, 2017; Whitney, 1994). In Iowa and portions of Minnesota, USA, wetlands have been drained, forests cut down and prairies removed in favour of agriculture and row crop production (Gallant, Sadinski, Roth, & Rewa, 2011; Smith, 1981). This shift towards intensive agriculture has also included considerable modifications to naturally flowing streams. Many streams in the region now consist of vast channelized reaches and headwaters made up of drainage ditches to aid in irrigation, removal of excess water from fields and flood control (Bishop, 1981; Waters, 1977). The straightening and channelization of rivers and streams affect not only the organisms inhabiting them but also affects the relationship between the stream and its floodplain (Blann, Anderson, Sands, & Vondracek, 2009; Geist & Hawkins, 2016; Hansen & Muncy, 1971; Junk, Bayley, & Sparks, 1989).

Collectively, these changes reduce the rate of formation and inundation of off-channel aquatic habitats (King, 1976). Oxbows are common off-channel habitats in Iowa and southern Minnesota (Bakevich, Pierce, & Quist, 2013; Kenney, 2013) and are formed over time by a stream's natural meandering process (Figure 1; Ward, Tockner, Arscott, & Claret, 2002; Charlton, 2008). Many naturally meandering stream reaches in Iowa and Minnesota have been artificially straightened, thus diminishing the rate of natural oxbow formation and resulting in the isolation and filling in of remaining floodplain oxbows.

In areas of Iowa and Minnesota where natural streams have been substantially altered and channelized, oxbows are among the few remaining aquatic habitats with little or no flow in floodplains dominated by agriculture (Brookes, Gregory, & Hansen, 1983; Miller, Crumpton, & van der Valk, 2009). These habitats may be critical for many aquatic organisms, including fishes (Bakevich et al., 2013; Chessman, 1988; Ledwin, 2011; Morken & Kondolf, 2003). Oxbows are typically disconnected from the stream except during periods of flooding, when fishes can enter from and exit to adjacent streams. Over time, silt deposits from repeated flooding can reduce oxbow water depths (Ishii & Hori, 2016), increasing susceptibility to summer hypoxia and drying while also being prone to completely freezing in the winter (Escaravage, 1990), which can result in the elimination of fishes (Fischer, Bakevich, Shea, Pierce, & Quist, 2018; Townsend, Boland, & Wrigley, 1992). To prevent fish kills, state, federal and non-profit agencies in Iowa and Minnesota are restoring oxbows to a deeper, more original

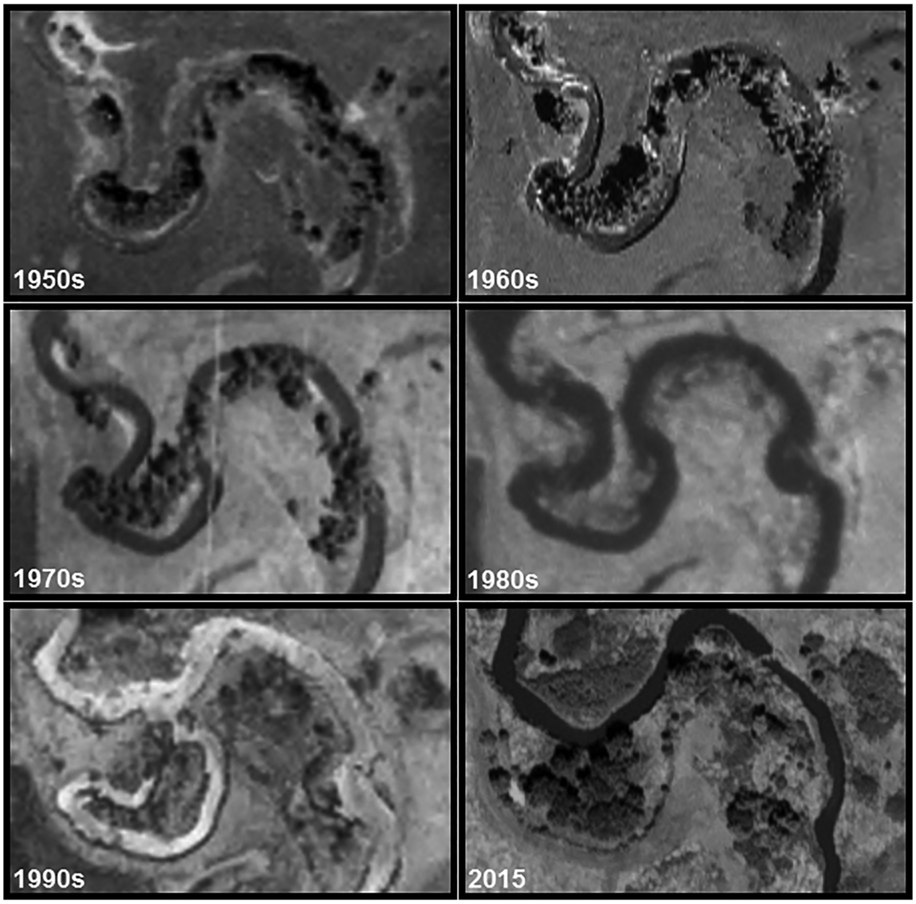

FIGURE 1 Aerial photos depicting natural oxbow formation over time, White Fox Creek, Woolstock, IA, USA. In the 1950s and 1960s the stream flowed through a horseshoe-shaped meander. Erosive forces caused a narrowing upstream and downstream of the meander in the 1970s and 1980s. In the 1990s the meander had become mostly disconnected from the stream. In 2015 the meander was completely disconnected from the stream as an oxbow (photo credit: Iowa State University Geographic Information Systems Support and Research Facility)

state (Kenney, 2013; Utrup, 2015). These efforts have resulted in more than 140 oxbow restorations in central and north-west Iowa and south-western Minnesota. The restoration process involves dredging out soil down to the depth of the old stream bed, resulting in increased water depths and reconnection to groundwater sources, which allows oxbows to hold water during droughts and potentially support fish year-round (Figure 2; Kenney, 2013). Oxbow restoration occurs globally and with several different goals. For instance, oxbows have been restored in areas such as Poland, the Netherlands and the USA to benefit benthic macroinvertebrates and rheophilic cyprinids and reduce nutrient load (Fink & Mitsch, 2007; Grift, Buijse, van Densen, & Klein Breteler, 2001; Obolewski & Glinska-Lewczuk, 2011). This project focused on oxbow restoration in Iowa and Minnesota for the purpose of endangered species conservation.

The Topeka shiner (*Notropis topeka*; Gilbert, 1884) is an example of a fish that has been adversely affected by the loss of slow-flowing stream habitats (USFWS, 2018). Once an abundant member of stream fish assemblages in Iowa, Kansas, Minnesota, Missouri, Nebraska, and South Dakota (Lee et al., 1980), the species has experienced declines in distribution and abundance over recent decades, resulting in their federal listing as an endangered species in 1998 (Tabor, 1998). Their preferred habitats of slow current, sand and gravel substrates, and instream vegetation have become rare in areas of agricultural land use (Pflieger, 1997; Rowe, Pierce, & Wilton, 2009). A primary goal of oxbow restorations in the Boone River, North Raccoon River, Rock River and Lower Big Sioux River basins in Iowa and Minnesota is to provide additional off-channel habitats for Topeka shiners that mimic the slow-current habitat that they prefer. Recent research has shown that Topeka shiners often use oxbow habitats, including both restored and naturally occurring, unrestored oxbows (Bakevich et al., 2013; Kenney, 2013). They are commonly sampled in heavily vegetated oxbows with riparian zones consisting mostly of grass and a few trees (Bakevich et al., 2013; Menzel & Clark, 2002); however, little is known regarding the differences in the density of Topeka shiners between restored and unrestored oxbow habitats or how several other oxbow characteristics (e.g. depth, length, canopy cover, water quality) affect their occurrence and abundance.

In addition to the physical characteristics of oxbows, understanding how resident fishes potentially influence the presence of Topeka shiners is critical when planning future habitat restoration. Several studies have suggested that Topeka shiner presence and abundance are positively associated with the presence of green sunfish (*Lepomis cyanellus;* Pflieger, 1997; Shearer, 2003), orangespotted sunfish (*Lepomis humilis;* Pflieger, 1997; Shearer, 2003; Campbell, Szuwalski, Tabor, & deNoyelles, 2016), and fathead minnows (*Pimephales promelas;* Bakevich et al., 2013) and negatively affected by the presence of piscivorous fish species (Mammoliti, 2002; Schrank, Guy, Whiles, & Brock, 2001; Winston, 2002), although coexistence with piscivores is not uncommon (Bakevich et al., 2013; Thomson & Berry, 2009). Thus, a better understanding of how fish assemblages affect the presence of Topeka shiners within oxbows in Iowa and Minnesota is needed.

Oxbow restoration is becoming a common practice throughout the Midwest for the conservation of Topeka shiners and other fishes of conservation concern, but little is known about the use of restored compared with unrestored oxbows by Topeka shiners or what types of oxbow habitats and fish assemblages are associated with their presence. Consequently, the objectives of this study were to assess Topeka shiner occurrence and abundance in restored and unrestored oxbows, and to evaluate the abiotic characteristics and fish assemblages associated with their presence. Potentially useful characteristics of oxbows as well as several other factors not examined in previous research were measured in an effort to determine abiotic and fish assemblage characteristics associated with Topeka shiner presence. A more complete understanding of the effects of local habitat and fish assemblage characteristics on them in oxbows of Iowa and Minnesota may help guide restoration projects to improve suitability and increase the chance of utilization by this imperilled cyprinid.

2 | METHODS

2.1 | Study basins

Oxbows were sampled within the Boone River and North Raccoon River basins in north-central Iowa, the Rock River basin extending from north-west Iowa into south-west Minnesota, and the Beaver Creek HUC 10 basin within the Lower Big Sioux basin in south-west

FIGURE 2 Example of oxbow pre- and post-restoration, White Fox Creek, Webster City, IA, USA (photo credit: Karen Wilke, The Nature Conservancy)

Minnesota (Figure 3). Basins ranged from 425 km^2 (Beaver Creek) to 6,395 km^2 (North Raccoon). Agricultural production accounted for 75–85% of land use in these basins and contributed to widespread stream straightening and channelization (Agren Inc., 2011; Onsrud et al., 2014; USDA, 2008). These basins are believed to be the only basins in Iowa and Minnesota currently holding Topeka shiners (USFWS, 2018).

Oxbow restoration has taken place in these basins for nearly two decades. Twenty-two oxbows have been restored in the Boone River basin. Over 60 oxbows have been restored in both the North Raccoon and Rock River basins, and six have been restored in the Beaver Creek basin. Both restored and unrestored oxbows were sampled in all basins except the Beaver Creek basin where only restored oxbows were sampled. Oxbows sampled were small, averaging 111.0 m (± 17.7 m; mean ± 95% confidence interval, CI) in length, 11.7 m (± 1.0 m) in width, and 0.6 m (± 0.6 m) in depth.

2.2 | Fish sampling

Fishes were collected with bag seines (10.7 × 1.8 m or 17.1 × 1.8 m, 6.35 mm mesh) from May to October in 2016–2017 following a protocol similar to that in Bakevich et al. (2013). Three passes were made with the seine in each oxbow, if possible, which was deemed sufficient to detect Topeka shiners, if present, given their high detection probability (>90%; Fischer et al., 2018). After each pass, all fishes were identified to species, counted and isolated from the oxbow until all passes were complete. All fishes were released alive back into the oxbow following the enumeration of all catches. In some oxbows, high densities of filamentous algae combined with unusually high catch rates of fishes increased sorting and processing time, which precluded the completion of three seine passes to reduce stress and mortality. However, if Topeka shiners were detected within an oxbow, they were mostly detected in the first seine pass (88% of oxbows) and were always detected by the second pass. Given their high detection probability, it is unlikely that they were not collected in an oxbow in which they were present.

For all oxbows, catch per unit effort (CPUE) was calculated for each species present as the number of individuals per 100 m^2 of sampled area. Because the number of seine passes was not consistent across all oxbow surveys based on sampling conditions, only individuals captured in the first seine pass were included in calculations of relative abundance; however, Topeka shiners were considered present if collected in any of the completed seine passes. CPUE was also calculated for groups of species such as nest associates of Topeka shiners (green sunfish and orangespotted sunfish; Campbell et al., 2016), piscivorous species (black crappie [*Pomoxis nigromaculatus*], largemouth bass [*Micropterus salmoides*], northern pike [*Esox lucius*], northern rock bass [*Ambloplites rupestris*], shortnose gar [*Lepisosteus platostomus*], smallmouth bass [*Micropterus dolomieu*], walleye [*Sander vitreus*], and white crappie [*Pomoxis annularis*]), and a total CPUE that included all species.

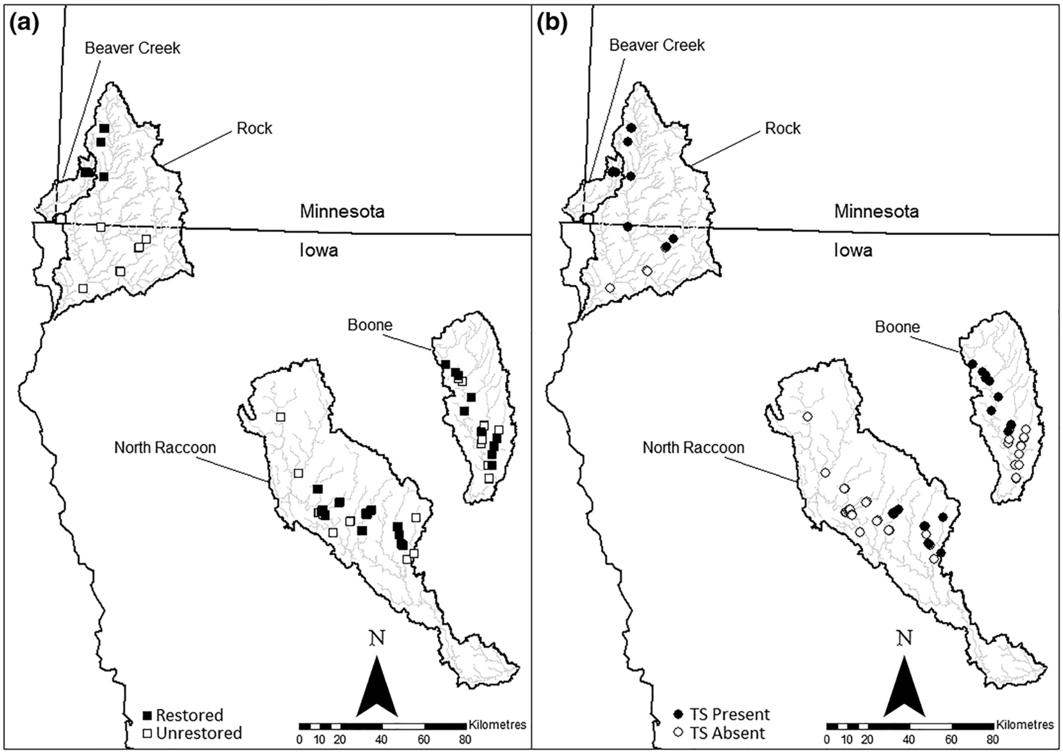

FIGURE 3 Oxbow sampling distribution in the Boone, Beaver Creek, North Raccoon and Rock River basins, Iowa and Minnesota, USA, in 2016–2017. (a) Oxbows that were restored (black squares) or unrestored (white squares). (b) Oxbows where Topeka shiners were present (black circles) or absent (white circles)

2.3 | Water quality and habitat sampling

Abiotic characteristics were measured once in each oxbow before fish sampling to ensure that the sample represented the undisturbed state. Water quality measurements were taken near the water surface and included temperature (°C), dissolved oxygen (mg L^{-1}), ambient conductivity (mS cm^{-1}; Yellow Springs Instruments, Professional Series model 2030), pH (Thermo Fisher Scientific, model pHTestr 10) and turbidity (NTU; Hach, model 2100Q portable turbidimeter). Habitat characteristics were measured following the Iowa Department of Natural Resources procedure for wadeable streams, modified for oxbow habitats (Iowa Department of Natural Resources, 2015). Measurements were taken at three transects within each oxbow spaced at 25, 50 and 75% of the wetted length. At each transect, wetted width was first measured. Depth (m) and substrate type (bedrock, boulder, riprap, cobble, gravel, sand, silt, soil, clay, muck, detritus, or wood) were measured at 10, 30, 50, 70 and 90% of the wetted width at each transect. Density of fish cover habitats (filamentous algae, macrophytes, woody material >0.3 m diameter, small brush <0.3 m diameter, tree roots, boulders, overhanging banks, undercut banks and artificial structures) was estimated in a 10 m area centred at each transect as either absent (0%), sparse (<10%), moderate (10–39%), heavy (40–75%), or very heavy (>75%). Bank angle was measured at each transect using a clinometer and the percentage of bare bank was visually estimated. Using a spherical densiometer, canopy cover was measured on each bank and at the midpoint of each transect. Riparian vegetation was visually estimated on each transect bank in a 10 × 10 m area into the riparian area from each transect. Type (deciduous, coniferous, broadleaf evergreen, mixed or none) and aerial coverage of vegetation were estimated for three height ranges – canopy (>5 m), understory (0.6–1.5 m) and ground cover (<0.5 m) – on each bank and recorded as absent (0%), sparse (<10%), moderate (10–39%), heavy (40–75%) or very heavy (>75%).

2.4 | Data analysis

To explore similarities or differences in fish assemblages and abiotic characteristics among oxbows, nonmetric multidimensional scaling (NMDS) ordinations were used to visualize oxbows in two-dimensional ordination space. Ordinations were plotted from distance matrices using Bray–Curtis distances after standardizing observations for site totals (Faith, Minchin, & Belbin, 1987). Minimum convex polygons were added to ordinations to better visualize patterns in ordination space. Vectors were added to ordinations for variables that were correlated with ordination axis values ($r \geq |0.5|$; Kirkman, Coffey, Mitchell, & Moser, 2004; Pietikäinen, Tikka, Valkonen, Isomäki, & Fritze, 2007). Standardization, distance matrices and ordinations were performed in PRIMER (Clarke & Gorley, 2006). Differences in fish assemblages and abiotic characteristics among restored and unrestored oxbows as well as differences among oxbows where Topeka shiners were present or absent were tested with analysis of variance using distance matrices (ADONIS).

Potential associations of fish assemblage and abiotic characteristics with the presence of Topeka shiners were investigated. In order to produce more accurate and interpretable models, all rare variables (occurring in <10% of oxbows) were eliminated and Pearson correlation coefficients were calculated for all pairs of remaining variables. In cases where two or more variables were highly correlated ($r \geq 0.70$), variables represented by vectors in NMDS ordinations were retained. If both highly correlated variables were not represented by vectors in ordination, only the more ecologically relevant or more easily interpreted variable was retained.

Random forest modelling was used to further reduce the number of variables used for modelling the presence or absence of Topeka shiners. Random forest modelling builds many decision trees without making distributional assumptions of the dataset and is able to process situations where there are more predictor variables than observations (Cutler et al., 2007). Random forest models are able to compute the rank importance of each predictor variable based upon how the model performs when each variable is excluded from the classification process. Variables with high importance rankings were included in further regression analysis. To determine whether Topeka shiner presence could be predicted with greater accuracy based on the inclusion of different types of variables, three model groups were developed, including (a) all variables, (b) only abiotic variables and (c) only the relative abundance of other fishes present in each oxbow. All variables included in each model are considered important for the presence of Topeka shiners; however, to further improve interpretation of these important variables, regression analysis was used to obtain coefficient estimates.

Logistic regression with the reduced set of variables identified with random forests was used to model the presence of Topeka shiners. Logistic regression is often used in ecology when the variable of interest is binary (present or absent; Jackson, Setsaas, Robertson, & Bennett, 2008; Groce & Morrison, 2010; Linde, 2010). An information theoretical approach was used, allowing conclusions to be drawn for a group of highly competitive candidate models rather than only the highest performing model (Burnham & Anderson, 2002). For each of three model groups, the variables that random forest models ranked as most important to predict Topeka shiner presence were included in logistic regression analysis. The number of variables used (n = 9) to create candidate model sets equalled 10% of the number of oxbows sampled (Harrell, Lee, Califf, Pryor, & Rosati, 1984; Harrell, Lee, & Mark, 1996). All combinations of these variables (n = 512) were included in a set of competing candidate logistic regression models that were ranked by Akaike's Information Criterion corrected for small sample size (AIC_c). Candidate models with a $\Delta AIC_c \leq 2$ are considered highly competitive with the top-performing model (Burnham & Anderson, 2002) and were included in top model sets. Model averaged coefficients and 95% confidence intervals were calculated for each variable to determine statistical significance. The information theoretic approach also produces a weight of evidence that each model is the best as an inference (Akaike weight (w_i); Burnham & Anderson, 2002). Akaike weights were used to calculate the variable relative importance weight (relative importance) for variables in top model sets by summing the Akaike weights for all candidate models included in top model sets where each variable was included (Burnham & Anderson, 2002). Variables with higher relative importance values are more important for explaining the presence of a species (Burnham & Anderson, 2002). Generally, variables with a relative importance ≥ 0.60 are considered important for predicting the presence of a species (Calcagno & de Mazancourt, 2010; Sindt, Quist, & Pierce, 2012; Spaanheden Dencker et al., 2017; Wagner, Harmon, & Seehausen, 2012). Thus, all variables with a relative importance ≥ 0.60 were considered important in predicting the presence of Topeka shiners.

To determine if sample year, restoration or some interaction between these variables had an effect on Topeka shiner CPUE, a mixed design analysis of variance (mixed ANOVA; Field, 2009) was used among oxbows sampled in 2016 and again in 2017. The 'control' group consisted of six oxbows that were restored before 2016 and were therefore restored during both sampling events. The 'experimental' group consisted of 11 oxbows that were restored during the winter of 2016–2017. Two experimental oxbows were sampled in 2016, whereas the remainder were dry for all or most of 2016 and were not sampled. All 11 experimental oxbows were sampled in 2017 following restoration. To meet the mixed ANOVA assumption of normally distributed residuals, CPUE values were transformed (Log_{10}) + 1. Statistical significance was determined at $\alpha = 0.05$. All statistical analyses except for ordinations were performed in the program R (R Core Team, 2016).

3 | RESULTS

In 2016–2017, fish, water quality and habitat surveys were conducted at 64 restored and 34 unrestored oxbows (Figure 3a). A total of 166,497 individual fish of 49 different species were collected, with 40 species and 123,995 individuals sampled in restored oxbows and 46 species and 42,502 individuals sampled in unrestored oxbows. An average of 189.8 (± 86.8; mean ± 95% CI) individuals were sampled per 100 m^2 in restored oxbows in the first seine pass compared with 61.7 (±54.7) individuals per 100 m^2 in unrestored oxbows. Topeka shiners were collected from 40 oxbows (Figure 3b), including 29 of 64 (45.3%) restored oxbows and 11 of 34 (32.4%) unrestored oxbows and represented the ninth most abundant and the 12th most commonly occurring species overall. An average of 0.75 (±0.31; mean ± 95% CI) Topeka shiners were sampled per 100 m^2 in unrestored oxbows compared with 6.73 (±5.10; mean ± 95% CI) Topeka shiners per 100 m^2 in restored oxbows (two-sample *t*-test: $P = 0.03$; Figure S1). Oxbows with Topeka shiners also had higher average species richness, 13.0 (±1.22; mean ±95% CI), than oxbows without Topeka shiners, 7.89 (±1.19; two sample *t*-test: $P \leq 0.001$; Figure S2).

All oxbows received either three seine passes (74 of 98 oxbows; 75.5%) or one seine pass (24 of 98; 24.5%). Topeka shiners were sampled in the first seine pass at 35 of 40 oxbows where they were eventually collected. Topeka shiners were detected in five additional oxbows in the second seine pass where they had been absent in the first pass but were not sampled for the first time in the third seine pass at any oxbows (Figure S3a). At oxbows where three passes were completed, 76% of Topeka shiners were collected in the first seine pass (Figure S3b). Moreover, 71% of the total catch was sampled in the first seine pass, across oxbows where three passes were completed (Figure S3b).

Results of NMDS ordination (Figure 4a) indicated significant differences in fish assemblages between restored and unrestored oxbows (ordination stress = 0.21; ADONIS $P = 0.01$). This ordination shows a large amount of overlap between oxbow types, but with restored oxbows showing more variation along the NMDS1 axis. Similarly, significant differences were seen in fish assemblages between oxbows with Topeka shiners present and absent (Figure 4b; stress = 0.21; $P = 0.001$). In oxbows without Topeka shiners, species assemblages were more variable than in oxbows where they were present. Despite these ordinations not showing any significantly correlated vectors, restored oxbows and oxbows where Topeka shiners were present typically had higher abundances of species commonly found in lentic habitats or areas with low flow, such as black bullhead (*Ameiurus melas*),

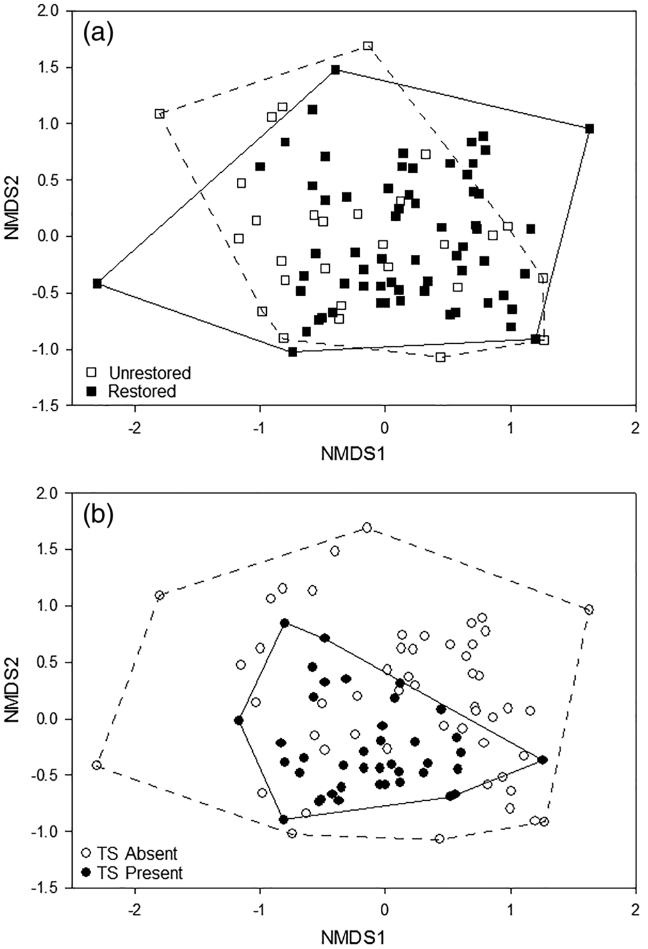

FIGURE 4 Nonmetric multidimensional scaling (NMDS) ordination of fish assemblages in (a) restored (black) vs. unrestored (white) oxbows, and (b) oxbows where Topeka shiners (TS) were present (black) and absent (white). No individual species was significantly correlated with the ordination; thus, no vectors are presented

brassy minnow (*Hybognathus hankinsoni*), common shiner (*Luxilus cornutus*) and orangespotted sunfish.

Abiotic characteristics also differed between restored and unrestored oxbows (Figure 5a; stress = 0.19; *P* = 0.001), with unrestored oxbows typically being further from the stream, with longer wetted lengths and higher amounts of canopy cover, woody riparian vegetation, small brush habitat and bank vegetation. However, abiotic characteristics were similar between oxbows with and without Topeka shiners present (Figure 5b; stress = 0.19; 0.06).

After removing rare and highly correlated variables, 47 variables were retained from the original list. Topeka shiner CPUE was excluded from models predicting Topeka shiner presence, leaving 46 variables for inclusion in random forest modelling to further reduce the variable set for logistic regression modelling. The lowest out-of-bag error was produced by the all-variables model (12.24%), followed by the fish abundance variables model (15.31%) and the abiotic variables model (32.65%), indicating that Topeka shiner presence is best modelled by random forests when including both local-scale abiotic and fish assemblage variables. Random forest models ranked the top nine most important variables in predicting Topeka shiner presence for each of the three models. The top predictor variables in the all-variables model consisted of eight fish assemblage variables (fathead minnow CPUE, brassy minnow CPUE, species richness, orangespotted sunfish CPUE, black bullhead CPUE, white sucker (*Catostomus commersoni*) CPUE, common shiner CPUE, and green sunfish CPUE) and one abiotic variable (dissolved oxygen). The top predictor variables in the abiotic variables model consisted of turbidity, years post restoration, macrophytes, wetted length, pH, distance to stream, dissolved oxygen, average wetted width and bare bank. The top predictor variables in the fish abundance variables model consisted of fathead minnow CPUE, brassy minnow CPUE, white sucker CPUE orangespotted sunfish CPUE, black bullhead CPUE, common shiner CPUE, central stoneroller (*Campostoma anomalum*) CPUE, green sunfish CPUE and brook stickleback (*Culaea inconstans*) CPUE.

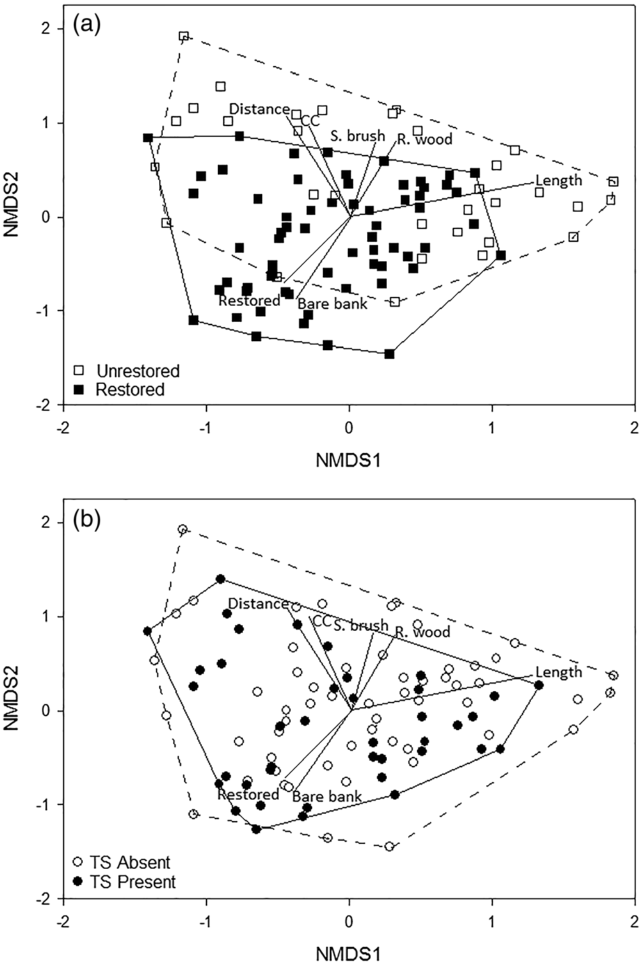

FIGURE 5 Nonmetric multidimensional scaling (NMDS) ordination of abiotic characteristics in (a) restored (black) vs. unrestored (white) oxbows and (b) oxbows where Topeka shiners (TS) were present (black) and absent (white). Vectors are shown for variables correlated with ordination ($r \geq 0.50$). Length of vectors indicate strength of relationships. Vector labels: distance, minimum distance to stream (m); CC, percentage of site with canopy cover; S. brush, estimated density of small brush; R. wood, estimated coverage of woody riparian vegetation; length, wetted length; bare bank, percentage of bare bank around oxbow; restored, oxbow restoration

The top model set for the all-variables model included 11 candidate models with $\Delta AIC_c \leq 2$ (Table 1). Species richness, brassy minnow CPUE and dissolved oxygen were common to all top candidate models. These variables each had positive associations with Topeka shiner presence and relative importance values of 1.00 (Table 2; Figure 6). Orangespotted sunfish CPUE was also considered important in predicting Topeka shiner presence with a relative importance value $\geq$0.60, but the slope of this relationship did not differ from zero (Table 2; Figure 6). Common shiner CPUE, green sunfish CPUE, black bullhead CPUE and white sucker CPUE were also identified as potentially important variables to predict Topeka shiner presence, but all had relative importance values <0.60 and the slopes of these relationships with Topeka shiner presence did not differ from zero (Table 2).

The top model set for the abiotic variables model included five candidate models (Table 1). Oxbow length and turbidity were common to all top candidate models, having relative importance values of 1.00 (Table 2). Increased oxbow length was negatively associated with Topeka shiner presence whereas increased turbidity was positively associated with Topeka shiner presence (Figure 6). Dissolved oxygen was also considered important in predicting Topeka shiner presence with a relative importance value $\geq$0.60, but the slope of the relationship did not differ from zero (Table 2; Figure 6). Average width, distance to stream and pH were also identified as potentially important to predict Topeka shiner presence, but all had relative importance values <0.60 and the slopes of these relationships with Topeka shiner presence did not differ from zero (Table 2).

The top model set for the fish abundance model included 15 candidate models (Table 1). Brassy minnow CPUE and orangespotted sunfish CPUE were common to all top candidate models, having positive associations with Topeka shiner presence and relative importance values of 1.00 (Table 2; Figure 6). White sucker CPUE, central stoneroller CPUE, black bullhead CPUE, common shiner CPUE, brook stickleback CPUE

TABLE 1 Top model sets for the all-variables, abiotic variables and fish abundance variables logistic regression models. Listed parameters are variables comprising each candidate model, number of parameters in each model (*k*; *n* + 2), Akaike's information criterion corrected for small sample size (AIC_c), change in AIC_c from top candidate model (ΔAIC_c), and Akaike's weight (w_i) of each model

Top models	*k*	AIC_c	ΔAIC_c	w_i
All-variables models				
Species richness, brassy minnow, common shiner, dissolved oxygen, orangespotted sunfish	7	103.62	0.00	0.14
Species richness, brassy minnow, dissolved oxygen, orangespotted sunfish	6	103.85	0.23	0.13
Species richness, brassy minnow, common shiner, dissolved oxygen, green sunfish, orangespotted sunfish	8	103.88	0.25	0.12
Species richness, black bullhead, brassy minnow, dissolved oxygen, orangespotted sunfish	7	104.53	0.91	0.09
Species richness, black bullhead, brassy minnow, dissolved oxygen	6	104.58	0.96	0.09
Species richness, brassy minnow, dissolved oxygen, green sunfish, orangespotted sunfish	7	104.60	0.98	0.09
Species richness, black bullhead, brassy minnow, dissolved oxygen, green sunfish, orangespotted sunfish	8	104.76	1.14	0.08
Species richness, black bullhead, brassy minnow, common shiner, dissolved oxygen, green sunfish, orangespotted sunfish	9	104.88	1.26	0.08
Species richness, black bullhead, brassy minnow, common shiner, dissolved oxygen, orangespotted sunfish	8	105.01	1.39	0.07
Species richness, black bullhead, brassy minnow, dissolved oxygen, green sunfish	7	105.08	1.46	0.07
Species richness, brassy minnow, common shiner, dissolved oxygen, orangespotted sunfish, white sucker	8	105.50	1.88	0.05
Abiotic variables models				
Dissolved oxygen, length, turbidity	5	135.71	0.00	0.37
Average width, dissolved oxygen, length, turbidity	6	136.99	1.27	0.19
Length, turbidity	4	137.32	1.61	0.16
Distance to stream, dissolved oxygen, length, turbidity	6	137.68	1.96	0.14
Dissolved oxygen, pH, length, turbidity	6	137.71	2.00	0.14
Fish abundance variables models				
Brassy minnow, orangespotted sunfish, white sucker	5	118.03	0.00	0.11
Brassy minnow, central stoneroller, orangespotted sunfish	5	118.10	0.07	0.10
Brassy minnow, orangespotted sunfish	4	118.14	0.10	0.10
Black bullhead, brassy minnow, orangespotted sunfish, white sucker	6	118.70	0.66	0.08
Brassy minnow, central stoneroller, orangespotted sunfish, white sucker	6	118.74	0.70	0.08
Black bullhead, brassy minnow, orangespotted sunfish	5	118.92	0.88	0.07
Black bullhead, brassy minnow, central stoneroller, orangespotted sunfish	6	118.97	0.93	0.07
Brassy minnow, common shiner, orangespotted sunfish, white sucker	6	119.32	1.29	0.05
Black bullhead, brassy minnow, central stoneroller, orangespotted sunfish, white sucker	7	119.50	1.47	0.05
Brassy minnow, brook stickleback, orangespotted sunfish, white sucker	6	119.51	1.48	0.05
Brassy minnow, brook stickleback, central stoneroller, orangespotted sunfish	6	119.51	1.48	0.05
Brassy minnow, brook stickleback, orangespotted sunfish	5	119.53	1.50	0.05
Brassy minnow, common shiner, orangespotted sunfish	5	119.59	1.55	0.05
Brassy minnow, central stoneroller, common shiner, orangespotted sunfish	6	119.78	1.74	0.04
Brassy minnow, green sunfish, orangespotted sunfish, white sucker	6	119.91	1.88	0.04

and green sunfish CPUE were also identified as potentially important for prediction of Topeka shiner presence, but all had relative importance values <0.60 and the slopes of these relationships with Topeka shiner presence did not differ from zero (Table 2).

A mixed ANOVA determined that group (control vs experimental; $F = 1.22$, $P = 0.277$) and year (2016 vs 2017; $F = 2.95$, $P = 0.096$) did not have significant effects on Topeka shiner CPUE; however, the interaction between group and year did affect Topeka shiner CPUE ($F = 9.55$, $P = 0.004$). Contrast statements between all combinations of group and year indicated that in 2017 Topeka shiner CPUE differed between the control and experimental oxbows ($t = -2.97$, $P = 0.006$; Figure 7). Topeka shiner CPUE also differed in the experimental oxbows between 2016 and 2017 samples ($t = -4.05$, $P < 0.001$; Figure 7). In addition, Topeka shiner CPUE in control oxbows in 2016 was marginally different than that in experimental oxbows in 2017 ($t = -2.00$, $P = 0.055$; Figure 7).

TABLE 2 Averaged coefficient estimates, standard errors, 95% confidence intervals and relative importance values for variables in top models sets

Model parameters	Estimate	SE	95% CI		Relative importance
All-variables models					
Brassy minnow[a]	0.040	0.015	0.012	0.069	1.00
Dissolved oxygen[a]	0.037	0.015	0.007	0.066	1.00
Species richness[a]	0.030	0.009	0.012	0.048	1.00
Orangespotted sunfish	0.005	0.003	−0.001	0.011	0.85
Black bullhead	0.001	0.001	−0.002	0.003	0.47
Common shiner	0.000	0.001	−0.001	0.001	0.46
Green sunfish	−0.001	0.002	−0.004	0.002	0.43
White sucker	0.000	0.002	−0.004	0.004	0.05
Abiotic variables models					
Length[a]	−0.001	0.001	−0.003	−0.000	1.00
Turbidity[a]	0.005	0.002	0.000	0.010	1.00
Dissolved oxygen	0.027	0.020	−0.012	0.067	0.84
Average width	0.002	0.006	−0.009	0.013	0.19
Distance to stream	0.000	0.000	−0.001	0.001	0.14
pH	−0.008	0.046	−0.097	0.082	0.14
Fish abundance variables models					
Brassy minnow[a]	0.040	0.016	0.009	0.071	1.00
Orangespotted sunfish[a]	0.007	0.002	0.002	0.012	1.00
White sucker	0.005	0.007	−0.010	0.020	0.46
Central stoneroller	0.005	0.008	−0.011	0.021	0.39
Black bullhead	0.000	0.001	−0.001	0.002	0.26
Brook stickleback	0.000	0.001	−0.003	0.002	0.15
Common shiner	0.000	0.000	−0.001	0.000	0.15
Green sunfish	0.000	0.000	−0.001	0.001	0.04

[a] Coefficient estimate is significantly different from 0.

4 | DISCUSSION

Based on logistic regression analysis, fish assemblage variables were more strongly associated with Topeka shiner presence than abiotic variables. The top model set of the all-variables model was dominated by fish assemblage variables, including seven fish assemblage variables and only one abiotic variable. Furthermore, error rates of random forest predictive models were comparable between the all-variables model (12.24%) and the fish abundance model (15.31%) while the abiotic variables model error rate was higher (32.65%). This complicates oxbow restorations for the conservation of Topeka shiners because fish assemblages are not as easily manipulated as habitat characteristics following restoration.

Topeka shiners were present more consistently and in higher abundances in restored oxbows than unrestored oxbows. This general pattern was evident for the majority of species sampled in 2016–2017. These results are in contrast to Fischer et al. (2018), who found Topeka shiners in only 20% of restored oxbows compared with 43% of unrestored oxbows; however, the much greater sample size of the present study ($n = 98$) compared with Fischer et al. (2018; $n = 12$) suggests that the present study is a better measure of the relative frequency of occurrence of Topeka shiners in restored and unrestored oxbows. Thus, restored oxbows appear to be successful in providing additional habitat for this species. In general, differences in fish assemblage and abiotic conditions were detected between restored and unrestored oxbows as well as between oxbows with Topeka shiners present and absent. Similar to Bakevich et al. (2013), Topeka shiners tended to be collected at sites with large relative abundances of species that are more adapted to lentic systems, including black bullhead, brassy minnow, common shiner, fathead minnow and orangespotted sunfish (Page & Burr, 2011), which tended to dominate assemblages in restored oxbows. In addition, regression modelling identified a positive association between Topeka shiner presence and fish species richness. A similar trend was documented in artificially created livestock ponds in South Dakota where ponds holding Topeka shiners had higher species richness than ponds without Topeka shiners (Thomson & Berry, 2009). Differences in abiotic characteristics between restored and unrestored oxbows such as wetted length, canopy cover and distance to stream were potentially a result of the current restoration strategy for Topeka shiners. The United States Fish and Wildlife Service (USFWS), which coordinates many oxbow restorations, currently prioritizes smaller restoration sites close to the stream and with few surrounding trees (A. Kenney, USFWS, personal communication). Some trees and other bank vegetation are also removed during restoration for heavy equipment access. Therefore, when analysing the associations of Topeka shiners, factors identified as important could be a function of restoration status rather than natural oxbow conditions.

Topeka shiner presence was positively associated with higher relative abundances of orangespotted sunfish and brassy minnows. This association with orangespotted sunfish has been previously documented and thought to be a product of nest association between the two species where Topeka shiners spawn over sunfish nests and rely upon male sunfish to protect and oxygenate the eggs while tending to their own (Campbell et al., 2016; Pflieger, 1997). Green sunfish have also been reported as a potential nest associate of Topeka shiner, but green sunfish CPUE was not significantly associated with Topeka shiner presence in this study. Topeka shiner associations with brassy minnow have been observed less frequently, although an association was noted by Fischer et al. (2018). Both species are associated with instream habitat dominated by slow current and vegetated backwaters (Carl, Clemens, & Lindsey, 1967; Nelson & Paetz, 1992; Page & Burr, 2011; Pflieger, 1997). Bakevich (2012) often found lentic species, including brassy minnow and Topeka shiner, together in oxbows and suggested that the two species are able to persist in harsh conditions that are common to oxbows throughout the year. In areas of Iowa and Minnesota with altered streams, it is possible that, with a decline in preferred instream

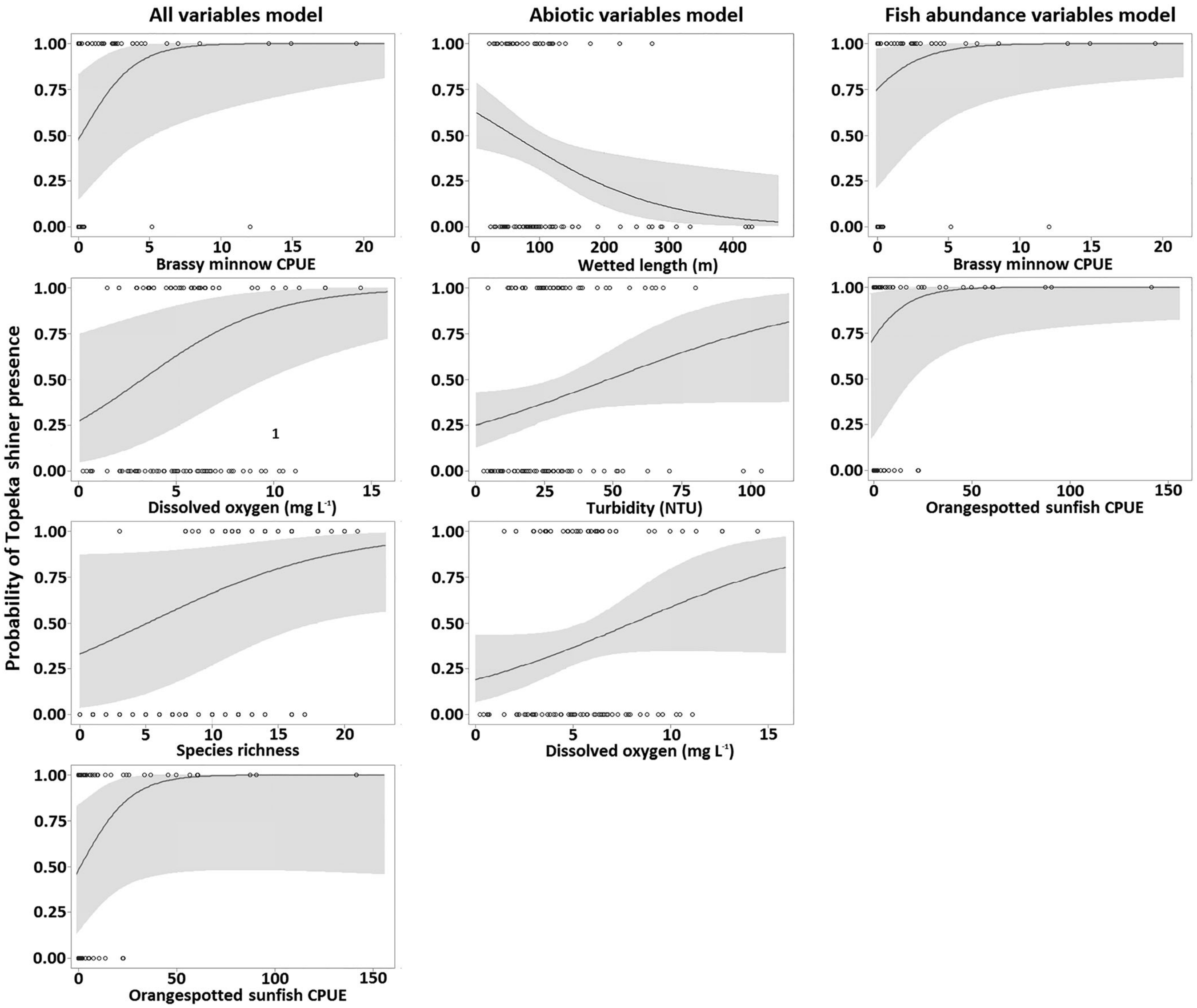

FIGURE 6 Logistic regression plots for variables important (relative importance ≥0.60) for Topeka shiners presence based on all variables (left), abiotic variables (centre), and fish abundance variables (right). Circles at zero on the *y*-axis represent oxbows where Topeka shiners were absent; circles at 1.0 on the *y*-axis represent oxbows where Topeka shiners were present. A curve depicts the probability of an oxbow holding Topeka shiners with all other top model set variables equal to their average value. Shaded region is 95% confidence interval of probability

habitats, Topeka shiners and brassy minnows both seek out oxbows as a substitute for instream pools and backwaters.

High dissolved oxygen levels were positively associated with Topeka shiner presence in oxbows. In the laboratory, Topeka shiners were tolerant of high temperature and low dissolved oxygen but experienced 50% mortality at 1.26 mg L^{-1} (Koehle & Adelman, 2007), a threshold observed only in oxbows not supporting Topeka shiners in this study. Moreover, fish in oxbows with higher dissolved oxygen levels may be less stressed and therefore less prone to disease (Braun, de Lima, Moraes, Lucia Loro, & Baldisserotto, 2006; Lushchak et al., 2005). It is important to note, however, that dissolved oxygen was measured only once in each oxbow. Daily and seasonal fluctuations in dissolved oxygen driven by ambient temperature, current weather, cloud cover, canopy cover and diel period (Lu, 2003) could have influenced fish assemblages in the oxbows sampled. Thus, interpretations of dissolved oxygen should be made with caution.

The probability of Topeka shiner presence in oxbows decreased with increasing wetted length, which may be a sampling artefact (i.e. restored oxbows averaged 81.4 + 10.8 m (95% CI) in length, whereas unrestored oxbows averaged 166.2 + 41.1 m). Because Topeka shiners were present more often in restored oxbows, analyses were unable to separate the two classifications. Smaller oxbows are typically targeted by biologists for restoration and are often dominated by cyprinids, whereas larger oxbows are typically thought to support a greater number of piscivores that could exert adverse impacts on Topeka shiners (A. Kenney, USFWS, personal communication; Mammoliti, 2002). However, piscivores were sampled at nearly equal rates in 2016–2017 across all oxbows with Topeka shiners (1.97 ± 1.98 piscivores

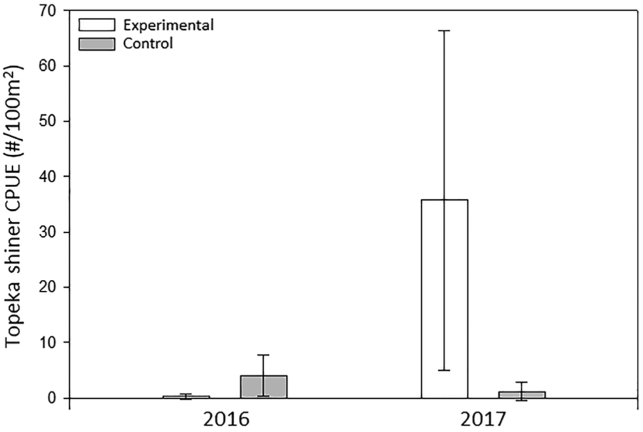

FIGURE 7 Mean Topeka shiner CPUE in experimental oxbows (restoration occurred between fish samples; white) and control oxbows (restored during both fish samples; grey) in 2016 and 2017. Error bars represent 95% confidence intervals

per 100 m^2 [mean ± 95% CI]) and without them (2.82 ± 2.91 piscivores per 100 m^2 [mean ± 95% CI]).

A practice that could be implemented following oxbow restorations to potentially increase use by Topeka shiners would be to stock oxbows with species they are often found with, such as brassy minnows and orangespotted sunfish. In Missouri, orangespotted sunfish are stocked into ponds along with hatchery raised Topeka shiners as a nesting associate (Straub, 2014). Another plausible interpretation is that managers need not be concerned with precisely matching certain abiotic criteria when restoring oxbows. As a result of the present restoration strategy, Topeka shiners used restored oxbows in greater abundance than unrestored oxbows. It might be beneficial to create experimental oxbow restorations with very diverse abiotic conditions to determine any factors that greatly increase Topeka shiner use.

Topeka shiners tended to be present in high abundances in oxbows less than one year following restoration. This study found that oxbows restored in the winter of 2016–2017 and then sampled in the summer of 2017 held the highest average Topeka shiner CPUE when compared with all restored and unrestored oxbows that were sampled twice in 2016–2017. These results demonstrate that Topeka shiner populations benefit quickly from oxbow restoration, making restoration an efficient management technique in areas of highly modified and channelized agricultural land by providing habitats that potentially act as a replacement for instream pools. Habitat restoration efforts have shown similar short-term successes following restoration for several types of wildlife, including coastal fisheries (Farrugia, Espinoza, & Lowe, 2014) and sage-grouse (Severson et al., 2017). The only way to determine whether these restorations continue to provide beneficial habitat for Topeka shiners will be a regular monitoring programme.

There are several factors that may have affected the results of the study. First, poor sampling conditions (i.e. seine obstructions, dense vegetation) of several unrestored oxbows led to lower sampling success in these systems. Many unrestored oxbows were shallow, had abundant aquatic macrophytes, and were surrounded by trees and other woody vegetation. These factors occasionally created difficult seining conditions, and sampling efficiency may have been affected. Second, Topeka shiner presence was associated with high turbidity, which may have been related to increased sampling efficiency (Aksnes & Utne, 1997). Non-turbid oxbows may have yielded lower numbers of all fishes because of greater gear avoidance. Species richness was higher in oxbows where Topeka shiners were present, suggesting that detection may have been due in part to sampling conditions. Third, time since the most recent inundation may have influenced sample composition, as more lotic species may be present in an oxbow immediately following a flooding event, and gradually perish over time (Bakevich et al., 2013). Fourth, the location of restored oxbows could have influenced the sampled assemblages. To increase their potential impact on known populations, restorations are typically performed in locations where Topeka shiners are present in the adjacent stream or other nearby oxbows (A. Kenney, USFWS, personal communication). To reduce this source of bias, unrestored oxbows were also sampled in these same areas when possible, but in many cases no unrestored oxbows were present or all were completely dry. Finally, we tried to reduce sampling bias by completing three seine passes in most oxbows. In oxbows where three passes were completed, Topeka shiners were sampled in the second seine pass in 10% of oxbows where they were not sampled in the first seine pass; however, three seine passes were not completed in all oxbows. Topeka shiners were recorded as absent at 13 oxbows where only one pass was completed. Assuming similar sampling results to oxbows where three passes were completed, Topeka shiners could have been present at 10% of these 13 oxbows, resulting in slightly different modelling results when comparing oxbows where Topeka shiners were present and absent; however, considering the size of the dataset any differences would probably be minor.

Restored oxbows frequently harbour significant populations of Topeka shiners in Iowa and south-west Minnesota, and the collective evidence to date suggests that restoring oxbows in this region will be an important strategy for recovery of this endangered species. Moreover, restored oxbows have displayed success in holding Topeka shiners since monitoring began in these systems close to a decade ago (Bakevich et al., 2013; Kenney, 2013; Utrup, 2015). Even with the positive effects of restoration, eventual delisting of Topeka shiners will require evidence of stable populations throughout its range. Thus, agencies in other states may consider similar restoration projects and monitoring programmes. In the present study, Topeka shiners were found more often and in higher abundance in restored oxbows compared with unrestored oxbows, but they were absent in oxbows averaging 128.3 m (±26.9 m; mean ± 95% CI) in length. It would be wise, therefore, to avoid restoration projects creating excessively long oxbows: not only could shorter restorations create habitat that better suits Topeka shiners, but this practice will also save in restoration cost as less soil will need to be excavated. In addition to short oxbows, it may also be useful to create oxbows with diverse abiotic conditions in an attempt to determine further what conditions potentially influence use by Topeka shiners. Topeka shiners also showed a positive association with orangespotted sunfish and brassy minnows. If possible, it would be helpful to conduct instream fish surveys or analyse available databases (Iowa Department of Natural Resources, 2018) before restoration projects are carried out to determine whether these species are present and able to populate a potential nearby oxbow. Biologists could also look for abundances of common shiner, green sunfish, black bullhead, white sucker, central stoneroller and brook stickleback as these species were all considered predictors of Topeka shiner presence in random forest models. Additional restorations and further research will be important in order to continue the successes seen since the addition of Topeka shiner to the endangered species list in 1998. As restoration practices continue to improve, the recovery of Topeka shiner becomes more likely.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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SUPPORTING INFORMATION

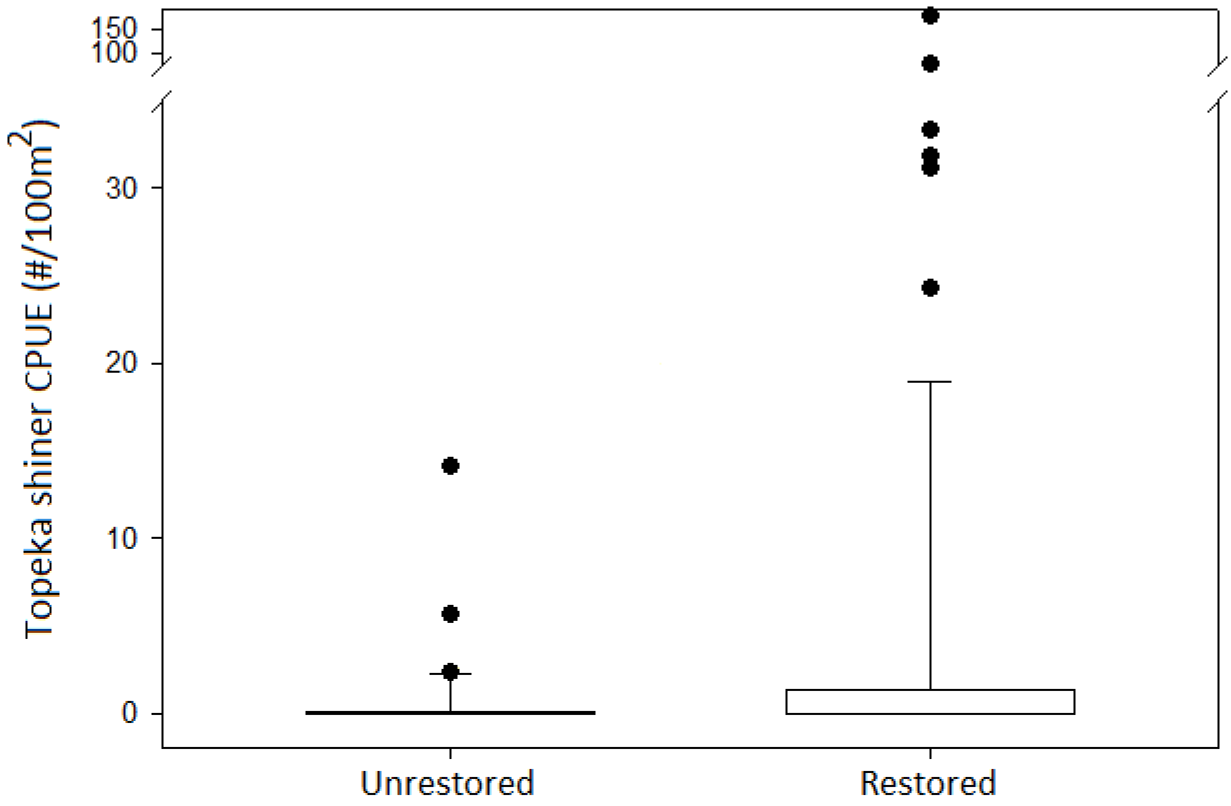

FIGURE S1. Topeka shiner CPUE (# per 100m^2) in restored and unrestored oxbows in Iowa and Minnesota, USA in 2016-2017. Boxes represent 25th-75th percentile, whiskers extend to 90th percentile, and dots represent outliers higher than 90th percentile in the dataset.

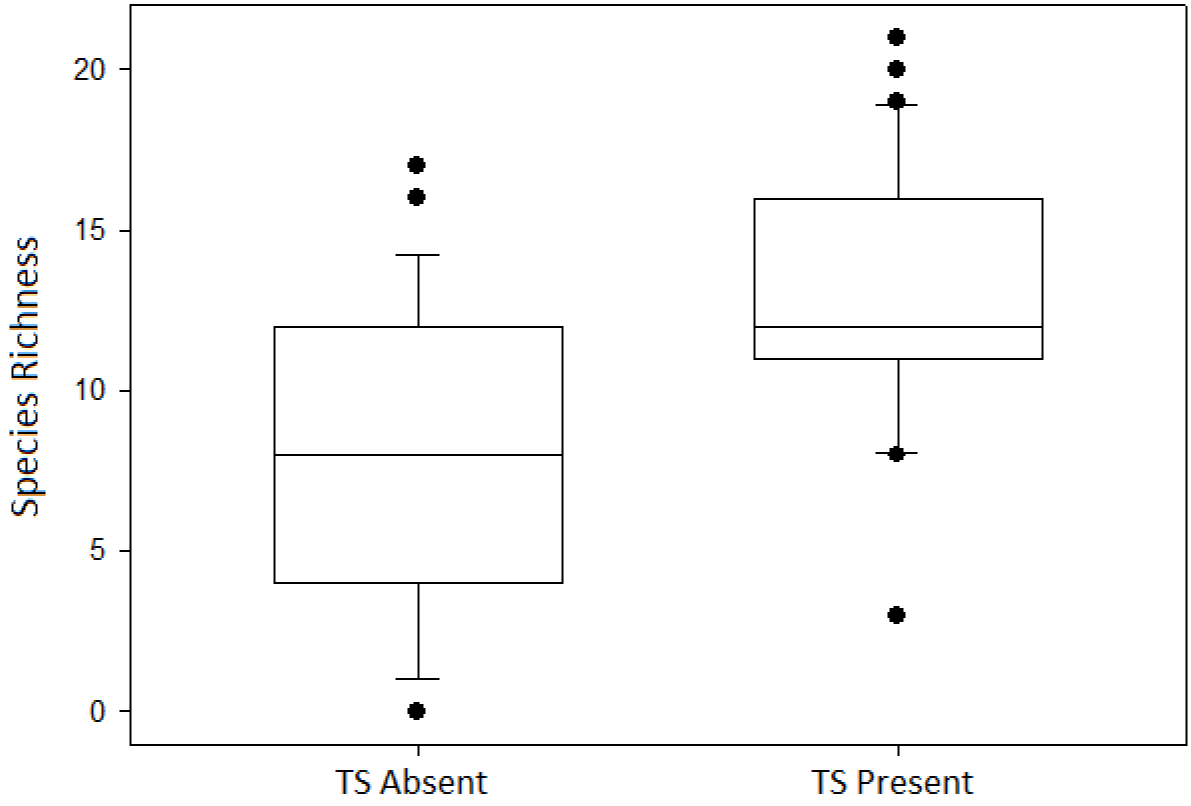

FIGURE S2. Species richness in oxbows where Topeka shiners (TS) were present and absent in Iowa and Minnesota, USA in 2016-2017. Boxes represent 25th-75th percentile, whiskers extend to 10th and 90th percentiles, and dots represent outliers lower than 10th percentile or higher than 90th percentile in the dataset.

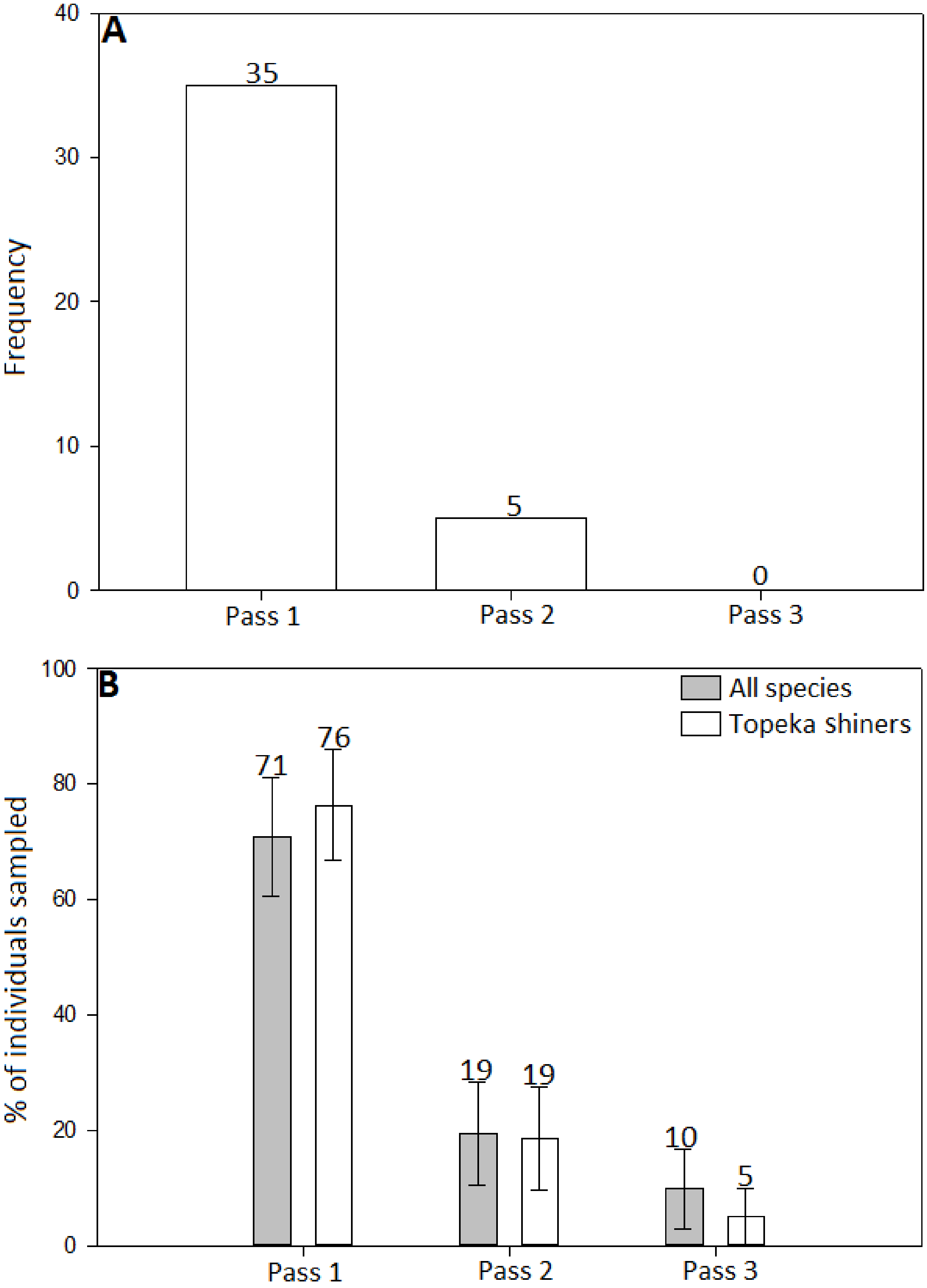

FIGURE S3. A) Number of oxbows where Topeka shiners were initially detected on the first seine pass, second seine pass, and third seine pass. B) Percentage of total individuals (Gray bars) and total Topeka shiners (White bars) sampled in the first seine pass, second seine pass, and third seine pass across all oxbows where three seine passes were completed. Error bars represent 95% confidence intervals.