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Research Article

Investigating the Fish Assemblages of the Neosho River System

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Barrier presence in river systems has been demonstrated to impair fish assemblages. Low head dams specifically are frequently occurring barriers in riverine environments. Well-supported impacts of these structures on fishes include diminished movement, reproduction, and habitat availability. Longitudinal patterns in riverine fish assemblages have long been researched to ascertain dynamics and display interactions. The need for research becomes more critical when factoring in impacts of barriers and detrimental invasive species. Knowledge of fish assemblages can inform fisheries biologists and aid in improved management practices for recreational and ecologically important species, as well as invasive species. The Neosho River system in Kansas has 14 barriers present. Little fisheries sampling has been done in the Kansas portion of this river system from the John Redmond Dam to the Oklahoma border; therefore, sampling was conducted to inform questions posed about the fish assemblages. We sought to document the fish assemblages of the system in Kansas and examine for assemblage composition distinctions by geographic region along a longitudinal gradient. The fish assemblage dataset from this research generated a wealth of knowledge on sportfish infiltration from reservoirs, imperiled fishes, and apparent impacts from low-head dams. Information from this study will aid in future management and direct new research investigating imperiled fishes.

1. Introduction

Freshwater ecosystems in North America have been modified by human activities for perceived economic and recreational benefits for hundreds of years [1–3]. Human alteration of freshwater environments has generated impacts such as pollution, habitat alteration, channelization, and introduced invasive or non-native species [2, 4–9]. One of the most common forms of anthropogenic modifications has been damming of lotic waters [2, 4, 6, 7, 9]. Dams can impair natural processes in freshwater ecosystems by creating hydrologic alterations, reducing discharge, altering sediment transport, modifying depth profiles, and homogenizing aquatic habitats [2, 3, 10, 11]. Limnological and ecological characteristics of lotic systems are altered following dam placement; more dam placement leads to more environmental alterations and can result in population fragmentation [11]. This is potentially harmful for lotic specialist fishes which have evolved best suited for unaltered systems [2, 12–16]. Proliferation of impounded rivers and streams in the past century has led to imperilment of many affected fish species [2]. One of the more deleterious impacts of dams on native lotic specialists has been impeded movement, including spawning migrations, and has led to population fragmentation [2, 3, 5, 8, 17–20].

Dams are often constructed to create reservoirs for perceived benefits such as flood control, hydroelectric power, mine wastes retention, and recreation [2, 3, 21]. These reservoirs alter habitat and hydrology, and in turn, the fish assemblages above, below, and within created reservoirs [15, 16, 20, 22, 23]. Fisheries biologists manage reservoirs for recreational angling and stock piscivorous fishes to provide opportunities to target "sportfish" at artificially high abundances, using barriers as population controls [20]. However, these recreationally important piscivorous sportfish can move (e.g., one-way and sometimes two-way) from reservoirs into lotic environments, subsequently disrupting native aquatic communities [20]. Negative impacts of dams on native riverine fishes are multifaceted; barriers impede movement and subsequent completion of life cycles when recreationally important reservoir sportfish bypass barriers, enter river ecosystems, and then compete with or consume native riverine species [2, 8, 10, 16, 20, 24].

Impacts from barriers can be further investigated by documenting fish assemblages along the longitudinal gradient of impaired aquatic systems [25–28]. As such, fish assemblages are often studied with a multigear approach to reduce sampling biases and obtain a representative sample [29–33]. Specifically, assemblages are often documented above and below barriers on longitudinal gradients and can allow assessment of impacts [2, 5, 16, 20, 34].

One aquatic system impaired by anthropogenic modification is the Neosho River system in Kansas. In 2023, there were 14 barriers (e.g., low head dams and earth-fill embankment dams) present that were constructed from 1870 to 1964 for flood control, hydroelectric, and municipal water supply purposes. Habitat and anthropogenic impacts vary longitudinally on this system because of the present barriers [2, 3]. Research on fish assemblages has taken place upstream of John Redmond Dam in the past few decades, but formal fish assemblage surveys are historically sparce in the stretch of river downstream of John Redmond Dam [35–38]. However, informal surveys have identified a broad fish assemblage that includes imperiled fishes (i.e., species in need of conservation (SINC) and threatened and endangered species (T&E)) and non-native species including Bighead Carp *Hypophthalmichthys nobilis* and Grass Carp *Ctenopharyngodon idella* [39–42]. The Neosho River system is also connected to reservoirs managed for recreational angling, including John Redmond Reservoir in Kansas and Grand Lake O' the Cherokees in Oklahoma. These reservoirs contain recreationally important piscivorous fishes defined as "sportfish" in Kansas (Table 1; [43–47]). Meanwhile, the invasive carp present in this system have perceived low population densities with unknown impacts [48, 49]. As such, establishing a baseline fish assemblage prior to potential invasion would allow biologists to measure effects in the future if invasive carp populations increase [50–55]. Influences listed above create a need to systematically describe fish assemblages across the gradient of the Neosho River.

We employed a suite of gears and conducted fisheries sampling above or below dams (where feasible) on the Neosho River system to document the fish assemblage at each location [33, 56]. Sites were grouped geographically to assess potential assemblage distinctions along a longitudinal gradient [25–28, 57, 58]. Our objectives for this project included establishing a protocol for long-term monitoring of the fish assemblages in the Neosho River basin, quantifying Neosho River system fish assemblages (i.e., establish baseline demographics), documenting and assessing imperiled fishes, investigating potential reservoir sportfish escapement, and examining for longitudinal distinctions in fish assemblages by the geographic region. We anticipated fish assemblage to change with river distance and expected sportfish and imperiled fishes abundance to relate to barriers and reservoirs. Results from this study (i.e., [59]) provide a previously undocumented assemblage dataset to fisheries biologists and insight on barrier impacts.

2. Methodology

2.1. Study Area. The Neosho River system is over 725 km long. We conducted fish assemblage sampling on approximately 375 km of the rivers from John Redmond Dam in Kansas to the Oklahoma border at 12 sites on the Neosho River system corresponding to access feasibility, landowner permissions, and barriers (Figure 1). We geographically divided the Neosho River into three regions (i.e., upper, middle, and lower) based on barrier concentration or isolation to assess possible fish assemblage distinction across a longitudinal gradient. Grand Lake O' the Cherokees and John Redmond Reservoir are reservoirs in closest proximity to lower and upper sites, respectively. In addition, upper, middle, and lower regions were differentiated a priori due to suppositions about each region. We perceived upper sites as tailrace influenced, middle sites as relatively uninfluenced, and lower sites as being influenced by Grand Lake O' the Cherokees.

2.2. Sampling. We sampled similarly to the long-term resource monitoring (LTRM) element used on the Upper Mississippi River system [33]. The number and placement of sets or runs varied at each site (Table 2). Set and run location remained fixed across seasons [33]. Location of set or run was modified corresponding to river condition with alternative placement locations established for adverse conditions (e.g., net moved to opposite riverbank to avoid deposited woody debris and net moved downstream 100 to 1,000 m to avoid dam turbulence) [33]. We also recorded coordinates at each gear and noted substrate type, macrohabitat type, the presence or absence of wing dams, large woody debris (i.e., snag), tributaries, and rip rap (i.e., boulders) [33]. Mini gill net and gill net sets were short-term (i.e., four hrs) when water temperature was above 16°C and overnight when water temperature was below 16°C. We differentiated sampling into seasons from June 2021 through November 2022 to assess possible seasonal variations. All observed fishes were netted regardless of species. Effort varied at some sites because of seasonal variation in river condition and expanse of the sampling area [33].

Effort of all passive gears ranged from one to four sets per site. We deployed AFS experimental gill nets either entirely parallel to shore with both ends of the net offshore, or with one end (small mesh portion) staked to shore, with the net stretched downstream. River conditions resulted in the determination of set type (e.g., net staked to shore in high current velocity) [33]. Similarly, we staked mini gill nets to shore and stretched either perpendicularly or downstream. These nets were 4.6 m in length and had one panel of 3.8 cm mesh. Hoop nets were set with the mouth (open end) facing downstream, were 1.1 m wide, were three m in length, and

Table 1: Presence or absence of 67 fish species found in the Neosho River drainage by sampling site from 2021 to 2022 via netting and day electrofishing.

Common name	John Redmond Dam	Burlington	Neosho Falls	Iola	Humboldt	Chanute 2	Chanute 3	Parsons	Oswego	Chetopa	Baxter Springs	Riverton-Empire Dam
Banded Darter										X	X	
Bigeye Shiner											X	X
Bullhead Minnow	X	X	X	X	X	X	X	X	X	X	X	X
Black Buffalo	X	X	X	X	X	X	X	X	X	X	X	X
*Black Bullhead												X
*Black Crappie	X						X			X		
Black Redhorse											X	
Brook Silverside	X		X	X		X			X	X	X	X
*Blue Catfish	X	X		X		X	X	X	X	X		
*Bluegill	X	X	X	X		X	X	X	X	X	X	X
Bigmouth Buffalo	X	X	X	X	X	X	X	X	X	X	X	X
Bluntnose Minnow	X	X	X	X		X	X	X	X	X	X	X
Blackstripe Topminnow		X									X	X
Blue Sucker	X	X	X			X		X				
Common Carp	X	X	X	X	X	X	X	X	X	X	X	X
Central Stoneroller											X	X
*Channel Catfish	X	X	X	X		X	X	X	X	X	X	X
Carmine Shiner	X		X	X						X	X	X
Emerald Shiner	X		X							X	X	X
*Flathead Catfish	X	X	X	X	X	X	X	X	X	X	X	X
Fathead Minnow						X	X	X	X	X		X
Freshwater Drum	X	X	X	X	X	X	X	X	X	X	X	X
Golden Redhorse											X	X
Golden Shiner		X										
*Green Sunfish	X	X	X	X		X	X	X	X	X	X	X
*Bluegill x Green Sunfish	X			X					X	X		
Grass Carp		X		X		X			X		X	
Gizzard Shad	X	X	X	X	X	X	X	X	X	X	X	X
Highfin Carpsucker									X	X	X	
Longear Sunfish	X		X	X		X	X	X	X	X	X	X
Logperch	X	X	X	X					X	X	X	X
*Largemouth Bass	X	X		X	X	X	X		X	X	X	X
Longnose Gar	X	X	X	X	X	X	X	X	X	X	X	X
Mimic Shiner	X	X	X	X		X	X	X	X	X	X	X
Western Mosquitofish	X		X			X		X	X		X	
Northern Hog Sucker										X		
Orangespotted Sunfish	X	X	X	X		X	X	X	X	X	X	X
Orangethroat Darter		X			X		X					
*Paddlefish	X	X				X						
Pealip Redhorse	X		X			X				X	X	X
Quillback											X	
Red Shiner	X	X	X	X	X	X	X	X	X	X	X	X
*Redear Sunfish x Bluegill									X			

Table 1: Continued.

Common name	John Redmond Dam	Burlington	Neosho Falls	Iola	Humboldt	Chanute 2	Chanute 3	Parsons	Oswego	Chetopa	Baxter Springs	Riverton-Empire Dam
*Redear Sunfish							X				X	X
*Rock Bass											X	X
Redspot Chub											X	
River Carpsucker	X	X	X	X	X	X	X	X	X	X	X	X
River Redhorse											X	X
*Striped x White Bass									X	X		
Spotfin Shiner											X	X
*Sauger x Walleye									X	X		
Slenderhead Darter	X											
Slim Minnow		X	X	X		X	X	X	X	X	X	X
Smallmouth Buffalo	X	X	X	X	X	X	X	X	X	X	X	X
*Smallmouth Bass										X	X	
Suckermouth Minnow		X		X	X				X	X		
Shortnose Gar	X	X	X	X		X	X	X	X	X	X	
Sand Shiner											X	X
Spotted Sucker										X	X	X
*Spotted Bass	X	X		X		X	X	X		X	X	X
Stonecat			X									
Spotted Gar						X		X	X	X	X	X
Threadfin Shad							X			X	X	
Tadpole Madtom		X			X				X			
*Warmouth									X	X	X	X
*White Bass	X	X	X	X		X	X	X	X	X	X	
*White Crappie	X	X	X	X		X	X		X	X	X	X

Kansas sportfish are denoted with an asterisk.

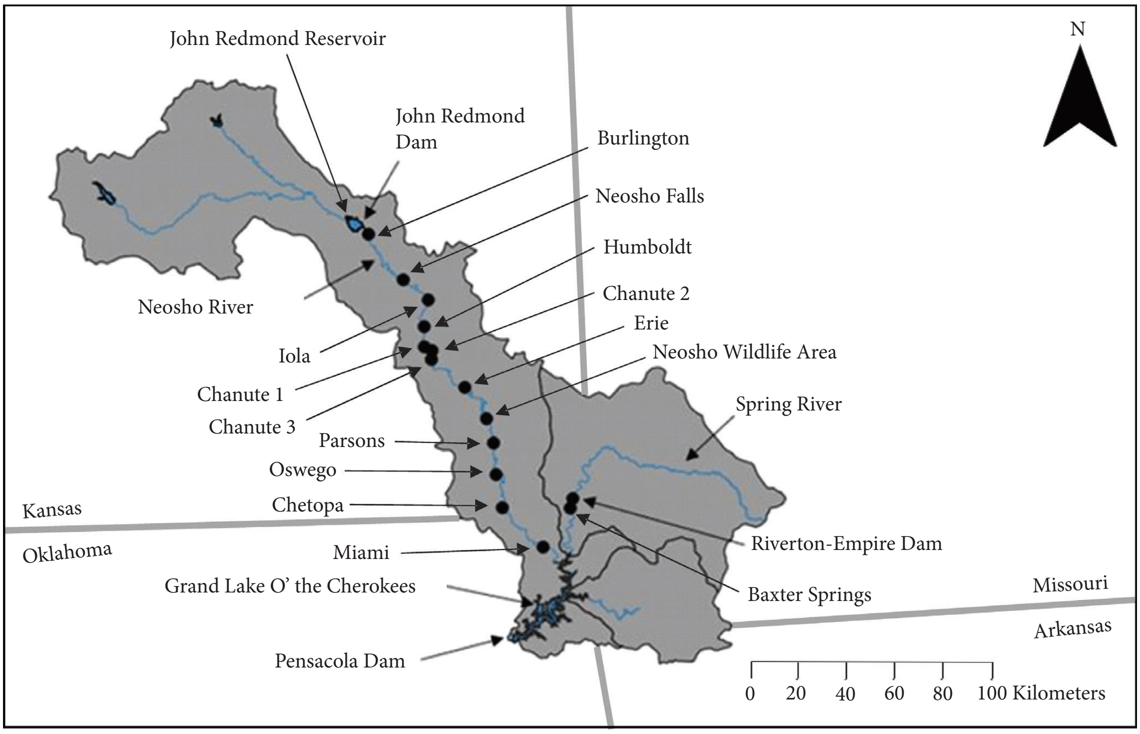

Figure 1: Map of the Neosho River system study area (adapted from [59]). Upper Neosho sites consist of John Redmond Dam, Burlington, Neosho Falls, and Iola. Middle Neosho sites include Humboldt, Chanute 2, and Chanute 3. Lower Neosho sites are Parsons, Oswego, and Chetopa.

had mesh that was 5.1 cm in width. We staked modified fyke nets to shore and extended nets perpendicularly to shore [33]. These nets had a lead that was 12.2 m in length and a frame that was 0.9 m by 1.5 m. Like that of modified fyke nets, we set mini fyke nets via stacking and subsequent stretching perpendicular to shore [33]. Mini fyke nets had mesh that was 0.3 cm in width, frames which were 0.6 m by 1.2 m, and a lead that was 6.1 m in length.

We used daytime pulsed-DC boat electrofishing via an ETS electrofishing control box (ETS Electrofishing Systems, LLC; Madison, WI); sampling effort consisted of 900 sec (15 min) "runs" [33]. All observed fishes were sought to be netted regardless of species. We set a goal of four or eight runs per site for standardization and achieved a power goal based on water temperature and conductivity [33]. Subsequently, sampling area availability and conditions contributed to electrofishing run variability [33]. While electrofishing, the boat was maneuvered according to LTRM, working downstream and into shorelines perpendicularly, and fishing low head dams as feasible [33]. Throughout sampling we sought to begin at a low head dam and work downstream or begin upstream and work down to a low head dam [33]. Runs of electrofishing either occurred by alternating bank position and maneuvering downstream (remaining on either river right or left for the entirety of one run before switching position) or were consecutively carried out while working downstream (sampling entirely on river right or left for half of the sampling effort before returning to the opposite bank of the initial starting point to additional shocking) [33].

2.3. Data Analyses.

Catch per unit of effort (CPUE; the number of fish captured per unit of effort) was standardized using multigear mean standardization (MGMS) to assess fish assemblage structure and composition. We used MGMS to incorporate CPUE from all gears into one metric because of complexities associated with using CPUE from multiple gears for assemblage analyses [61, 62]. Multigear mean standardization was calculated by determining a total CPUE of all species at each site for a given gear [61, 62]. Subsequently, the mean of each total CPUE was calculated and used for determining MGMS [61, 62]. The MGMS value for a species was obtained by dividing the CPUE for that species at a given site by the mean total CPUE [61, 62]. Values of MGMS were averaged across gears to account for potential variation and are a unitless value that serves as a proportion [61, 62].

Nonmetric multidimensional scaling (nMDS) (via program PAST version 4.03) was used to quantify variation in fish assemblages among sites or regions [26–28, 57, 61, 63, 64]. Dimensions (i.e., species) and samples (i.e., sites and regions) were accounted for nMDS on a two-dimensional plane with distance-related indices. Distance between sites or regions and species was ranked and preserved within the scope of nMDS. While nMDS was used to visually display potential similarities or distinctions by site or region via corresponding drivers (i.e., species), classical clustering provided another means for visual delineation. As such, classical clustering expanded on nMDS by defining which sites were most similar outside of regional associations not necessarily addressed in nMDS by

Table 2: Sampling effort by gear type (i.e., total sets for net gears, hrs for electrofishing) from all sites on the Neosho River system from 2021 to 2022.

Gear	John Redmond Dam	Burlington	Neosho Falls	Iola	Humboldt	Chanute 2	Chanute 3	Parsons	Oswego	Chetopa	Baxter Springs	Riverton-Empire Dam
Overnight gill sets	5	3									3	3
Short-term gill sets	9	5	5	7		6	6	6	9	12	13	5
Overnight mini gill sets	2	4									2	2
Short-term mini gill sets	6	2	2	6		4	4	6	4	8	10	2
Hoop sets	11	6	2	5		4	4	4	6	8	9	4
Modified fyke sets	9	5	2	5		4	4	4	6	8	9	5
Mini fyke sets	18	14	8	11		8	8	8	12	16	18	10
Electrofishing hrs	7.3	3.3	2.0	6.5	1.0	4.0	2.3	6.0	4.0	6.8	7.3	3.8

Short-term sets were four hrs; all other sets were overnight.

Table 3: Relative abundance (%) and frequency of occurrence (%) of 67 species observed at 12 sampling sites on the Neosho River system from 2021 to 2022.

Common name	*N*	Sites present	Relative abundance (%)	Frequency of occurrence (%)
Gizzard Shad	7,183	12	25.9	100.0
Red Shiner	4,750	12	17.2	100.0
Bullhead Minnow	1,573	12	5.7	100.0
Freshwater Drum	1,499	12	5.4	100.0
Mimic Shiner	1,420	11	5.1	91.7
Smallmouth Buffalo	1,279	12	4.6	100.0
Carmine Shiner	1,121	6	4.0	50.0
White Bass	1,097	10	4.0	83.3
Bluegill	916	11	3.3	91.7
White Crappie	700	10	2.5	83.3
Longnose Gar	599	12	2.2	100.0
Orangespotted Sunfish	565	11	2.0	91.7
Channel Catfish	553	11	2.0	91.7
River Carpsucker	481	12	1.7	100.0
Bluntnose Minnow	456	11	1.6	91.7
Common Carp	429	12	1.5	100.0
Black Buffalo	418	12	1.5	100.0
*Flathead Catfish	415	12	1.5	100.0
Shortnose Gar	351	10	1.3	83.3
Bigmouth Buffalo	194	12	0.7	100.0
Slim Minnow	178	10	0.6	83.3
Longear Sunfish	150	10	0.5	83.3
Pealip Redhorse	144	6	0.5	50.0
Brook Silverside	113	8	0.4	66.7
Spotted Bass	108	9	0.4	75.0
Emerald Shiner	105	5	0.4	41.7
Spotted Gar	103	6	0.4	50.0
*Blue Catfish	91	8	0.3	66.7
Fathead Minnow	85	6	0.3	50.0
Logperch	75	8	0.3	66.7
Spotfin Shiner	68	2	0.2	16.7
Largemouth Bass	65	10	0.2	83.3
Green Sunfish	59	11	0.2	91.7
Highfin Carpsucker	51	3	0.2	25.0
Western Mosquitofish	45	6	0.2	50.0
Spotted Sucker	23	3	0.1	25.0
Threadfin Shad	23	3	0.1	25.0
Blue Sucker	18	5	0.1	41.7
Black Redhorse	18	1	0.1	8.3
Redear Sunfish	16	3	0.1	25.0
Warmouth	15	4	0.1	33.3
Grass Carp	14	5	0.1	41.7
*Black Crappie	12	3	<0.1	25.0
Suckermouth Minnow	10	5	<0.1	41.7
Bigeye Shiner	9	2	<0.1	16.7
Paddlefish	8	3	<0.1	25.0
Banded Darter	8	2	<0.1	16.7
Golden Redhorse	8	2	<0.1	16.7
River Redhorse	7	2	<0.1	16.7
Orangethroat Darter	6	3	<0.1	25.0
Striped x White Bass	6	2	<0.1	16.7
Quillback	6	1	<0.1	8.3
Bluegill x Green Sunfish	5	4	<0.1	33.3
*Smallmouth bass	5	2	<0.1	16.7
Blackstripe Topminnow	4	3	<0.1	25.0
Tadpole Madtom	3	3	<0.1	25.0
*Rock Bass	3	2	<0.1	16.7
Sauger x Walleye	3	2	<0.1	16.7

Table 3: Continued.

Common name	*N*	Sites present	Relative abundance (%)	Frequency of occurrence (%)
Sand Shiner	3	2	<0.1	16.7
Redear Sunfish x Bluegill	3	1	<0.1	8.3
Central Stoneroller	2	2	<0.1	16.7
Black Bullhead	1	1	<0.1	8.3
Golden Shiner	1	1	<0.1	8.3
Northern Hog Sucker	1	1	<0.1	8.3
Redspot Chub	1	1	<0.1	8.3
Slenderhead Darter	1	1	<0.1	8.3
Stonecat	1	1	<0.1	8.3
Total	27,683			

Kansas sportfish not historically native to the Neosho River system are denoted with an asterisk.

Table 4: Netting effort, catch, and catch per unit of effort (CPUE) from the Neosho River from 2021 to 2022.

	Spring 2022	Summer 2021-2022	Fall 2021-2022	Total
Netting effort				
Overnight gill sets	6	2	—	8
Short-term gill sets	—	38	27	65
Overnight mini gill sets	4	2	—	6
Short-term mini gill sets	—	24	18	42
Hoop sets	4	28	18	50
Modified fyke sets	4	26	17	47
Mini fyke sets	8	53	42	103
Total samples (sets)	26	173	122	321
Netting catch				
Overnight gill	148	83	—	231
Short-term gill	—	120	113	233
Overnight mini gill	10	18	—	28
Short-term mini gill	—	14	13	27
Hoop	8	44	22	74
Modified fyke	6	79	100	185
Mini fyke	228	4,122	6,334	10,684
Total (*N*)	400	4,480	6,582	11,462
Total species	21	39	38	44
Netting CPUE (fish/net)				
Overnight gill	24.7 (5.2)	41.5 (6.5)	—	28.9 (4.8)
Short-term gill	—	3.2 (0.6)	4.2 (0.7)	3.6 (0.4)
Overnight mini gill	2.5 (1.0)	9.0 (7.0)	—	4.7 (2.4)
Short-term mini gill	—	0.6 (0.2)	0.7 (0.3)	0.6 (0.2)
Hoop	2.0 (2.0)	1.6 (0.3)	1.2 (0.6)	1.5 (0.3)
Modified fyke	1.5 (0.6)	3.0 (1.0)	5.9 (1.4)	3.9 (0.8)
Mini fyke	28.5 (9.4)	77.8 (34.5)	150.8 (74.9)	103.7 (35.3)
Total	15.4 (3.9)	25.7 (10.8)	54.0 (26.4)	35.7 (11.6)

Standard error is in parentheses.

organizing sites in a dendrogram. We performed classical clustering via a paired group (UPGMA) algorithm in program PAST (version 4.03) with MGMS values for this purpose [63]. We used the Bray-Curtis similarity index to compare sites and regions to species within both analyses and removed the Humboldt site because of a small sample size.

3. Results

We observed a total of 67 fish species from 13 families constituting 27,683 individual captures during all sampling on the Neosho River system (Table 1). Subsequently, species found at all 12 sampling sites included Bullhead Minnow, *Pimephales vigilax*; Black Buffalo, *Ictiobus niger*; Bigmouth Buffalo, *Ictiobus cyprinellus*; Common Carp, *Cyprinus carpio*; Flathead Catfish, *Pylodictis olivaris*; Freshwater Drum, *Aplodinotus grunniens*; Gizzard Shad, *Dorosoma cepedianum*; Longnose Gar, *Lepisosteus osseus*; Red Shiner, *Cyprinella lutrensis*; River Carpsucker, *Carpiodes carpio*; and Smallmouth Buffalo, *Ictiobus bubalus*. The two most prevalent species we observed in terms of relative abundance (%) were Gizzard Shad (25.9) and Red Shiner (17.2) (Table 3).

Effort and catch were combined for both years of summer and fall sampling via netting and electrofishing. We

Table 5: Electrofishing effort, catch, and catch per unit of effort (CPUE) from the Neosho River from 2021 to 2022.

	Spring 2022	Summer 2021-2022	Fall 2021-2022	Total
Electrofishing effort				
Samples (runs)	30	85	57	172
Electrofishing hrs	7.5	21.3	14.3	43.0
Electrofishing catch				
Total (*N*)	4,316	2,496	3,578	10,390
Total species	36	33	43	47
CPUE (fish/hr)	575.5 (387.4)	117.5 (9.2)	251.1 (68.4)	241.6 (71.6)

Standard error is in parentheses.

Table 6: Electrofishing effort, catch, and catch per unit of effort (CPUE) from upper, middle, and lower portions of the Neosho River from 2021 to 2022.

	Upper	Middle	Lower
Electrofishing effort			
Samples (runs)	76	29	67
Electrofishing hrs	19.0	7.3	16.8
Electrofishing catch			
Total (*N*)	6,572	1,024	2,794
Total species	36	34	41
CPUE (fish/hr)	345.9 (158.9)	141.2 (30.3)	166.8 (32.2)

Standard error is in parentheses.

Table 7: Netting effort, catch, and catch per unit of effort (CPUE) from upper, middle, and lower portions of the Neosho River from 2021 to 2022.

	Upper	Middle	Lower
Netting effort			
Overnight gill sets	8	—	—
Short-term gill sets	26	12	27
Overnight mini gill sets	6	—	—
Short-term mini gill sets	16	8	18
Hoop sets	24	8	18
Modified fyke sets	21	8	18
Mini fyke sets	51	16	36
Total samples (sets)	152	52	117
Netting catch			
Overnight gill	231	—	—
Short-term gill	122	56	55
Overnight mini gill	28	—	—
Short-term mini gill	15	8	4
Hoop	41	7	26
Modified fyke	82	58	45
Mini fyke	3,041	5,246	2,397
Total (*N*)	3,560	5,375	2,527
Total species	39	30	31
Netting CPUE (fish/net)			
Overnight gill	28.9 (4.8)	—	—
Short-term gill	4.7 (0.9)	4.7 (0.8)	2.0 (0.3)
Overnight mini gill	4.7 (2.4)	—	—
Short-term mini gill	0.9 (0.4)	1.0 (0.5)	0.2 (0.2)
Hoop	1.7 (0.5)	0.9 (0.4)	1.4 (0.5)
Modified fyke	3.9 (1.3)	7.3 (2.7)	2.5 (0.6)
Mini fyke	59.6 (23.3)	327.9 (191.3)	66.6 (39.8)
Total	23.4 (8.1)	103.4 (61.3)	21.6 (12.4)

Standard error is in parentheses.

Table 8: Netting effort, catch, and catch per unit of effort (CPUE) from the Spring River from 2021 to 2022.

	Spring 2022	Summer 2021-2022	Fall 2021-2022	Total
Netting effort				
Overnight gill sets	6	—	—	6
Short-term gill sets	—	12	6	18
Overnight mini gill sets	4	—	—	4
Short-term mini gill sets	—	8	4	12
Hoop sets	4	5	4	13
Modified fyke sets	4	6	4	14
Mini fyke sets	8	12	8	28
Total samples (sets)	26	43	26	95
Netting catch				
Overnight gill	73	—	—	73
Short-term gill	—	33	25	58
Overnight mini gill	3	—	—	3
Short-term mini gill	—	3	1	4
Hoop	9	5	6	20
Modified fyke	14	61	38	113
Mini fyke	154	818	71	1,043
Total (*N*)	253	920	141	1,314
Total species	29	34	25	42
Netting CPUE (fish/net)				
Overnight gill	12.2 (4.6)	—	—	12.2 (4.6)
Short-term gill	—	2.8 (1.7)	4.2 (1.6)	3.2 (1.2)
Overnight mini gill	0.8 (0.5)	—	—	0.8 (0.5)
Short-term mini gill	—	0.4 (0.2)	0.3 (0.3)	0.3 (0.1)
Hoop	2.3 (1.1)	1.0 (0.3)	1.5 (0.7)	1.5 (0.4)
Modified fyke	3.5 (2.4)	10.2 (3.8)	9.5 (4.1)	8.1 (2.1)
Mini fyke	19.3 (13.2)	68.2 (31.2)	8.9 (2.6)	37.3 (14.5)
Total	9.7 (4.3)	21.4 (9.6)	5.4 (1.2)	13.8 (4.5)

Standard error is in parentheses.

Table 9: Electrofishing effort, catch, and catch per unit of effort (CPUE) from the Spring River from 2021 to 2022.

	Spring 2022	Summer 2021-2022	Fall 2021-2022	Total
Electrofishing effort				
Samples (runs)	8	23	13	44
Electrofishing hrs	2.0	5.8	3.3	11.0
Electrofishing catch				
Total (*N*)	450	1,955	2,112	4,517
Total species	35	44	48	52
CPUE (fish/hr)	225.0 (21.8)	340.0 (58.4)	649.9 (99.1)	410.6 (48.3)

Standard error is in parentheses.

Table 10: Species in need of conservation (SINC) and threatened species (i.e., Redspot Chub) according to the Kansas Department of Wildlife and Parks in terms of number encountered during boat electrofishing and netting and their respective relative abundance (%).

	Neosho River		Spring River		Total	
	N	Relative abundance (%)	*N*	Relative abundance (%)	*N*	Relative abundance (%)
Banded Darter	2	<0.1	6	0.1	8	<0.1
Bigeye Shiner	0	—	9	0.2	9	<0.1
Black Redhorse	0	—	18	0.3	18	0.1
Blue Sucker	18	0.1	0	—	18	0.1
Highfin Carpsucker	7	<0.1	44	0.8	51	0.2
Northern Hog Sucker	0	—	1	<0.1	1	<0.1
Redspot Chub	0	—	1	<0.1	1	<0.1
River Redhorse	0	—	7	0.1	7	<0.1
Spotfin Shiner	0	—	68	1.2	68	0.2
Spotted Sucker	6	<0.1	17	0.3	23	0.1
Tadpole Madtom	3	<0.1	0	—	3	<0.1

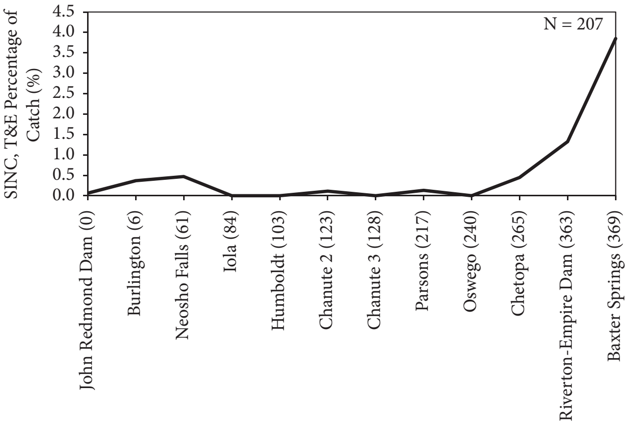

FIGURE 2: Species in need of conservation (SINC) and threatened and endangered (T&E) species percentage of catch from sampling sites on the Neosho River system. River distance in kilometers from John Redmond Dam is displayed in parentheses at each sampling location (i.e., barrier).

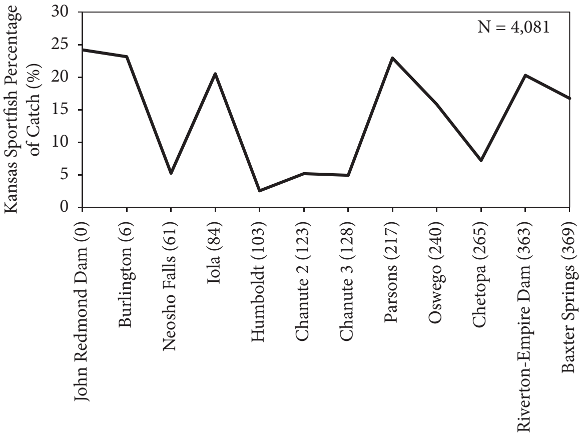

FIGURE 3: Kansas sportfish percentage of catch from sampling sites (i.e., dams) on the Neosho River system. River distance in kilometers from John Redmond Dam is displayed in parentheses at each sampling location. John Redmond Reservoir is directly upstream of John Redmond Dam. Grand Lake O' the Cherokees is 36 km downstream of Baxter Springs Dam and 61 km downstream of Chetopa Dam.

set 321 nets on the Neosho River and captured 11,462 fishes and 44 species (Table 4). Our overall effort and CPUE in terms of total fish/net (standard error (SE) in parentheses) included eight overnight gill nets (28.9 (4.8)), 65 short-term gill nets (3.6 (0.4)), six overnight mini gill nets (4.7 (2.4)), 42 short-term mini gill nets (0.6 (0.2)), 50 hoop nets (1.5 (0.3)), 47 modified fyke nets (3.9 (0.8)), and 103 mini fyke nets (103.7 (35.3)). Notably, mini fyke nets accounted for 93.2% of the total netting catch. Our most encountered fish species and the number of their captures by gear type included 121 Shortnose Gar *Lepisosteus platostomus* via gill netting, 26 Longnose Gar via mini gill netting, 21 Flathead Catfish from hoop nets, 43 White Crappie *Pomoxis annularis* from modified fyke nets, and 3,810 Red Shiners from mini fyke nets. We conducted 43.0 hrs (172 runs) of pulsed-DC boat electrofishing on the Neosho River and observed 10,390 fishes and 47 species (241.6 (71.6 SE) fish/hr) (Table 5). Electrofishing generated the greatest fish diversity among gears used on the Neosho River; Gizzard Shad, Freshwater Drum, and Smallmouth Buffalo were the three most encountered species. Spring electrofishing resulted in the greatest electrofishing CPUE (575.5 (384.4 SE) fish/hr), while fall produced the greatest number of captures via netting (i.e., 6,582 fishes). In addition, Upper Neosho had the greatest CPUE from electrofishing (345.9 (158.9 SE) fish/hr), while Middle Neosho generated the most observations via netting (i.e., 5,375 fishes; Tables 6 and 7).

We deployed 95 nets on the Spring River and observed 1,314 fishes (42 species) (Table 8). Gears used across all seasons and the corresponding effort and CPUE (total fish/net; SE in parentheses) included six overnight gill nets (12.2 (4.6)), 18 short-term gill nets (3.2 (1.2)), four overnight mini gill nets (0.8 (0.5)), 12 short-term mini gill nets (0.3 (0.1)), 13 hoop nets (1.5 (0.4)), 14 modified fyke nets (8.1 (2.1)), and 28 mini fyke nets (37.3 (14.5)). Mini fyke netting comprised a large portion of the total catch (i.e., 79.4%) similar to

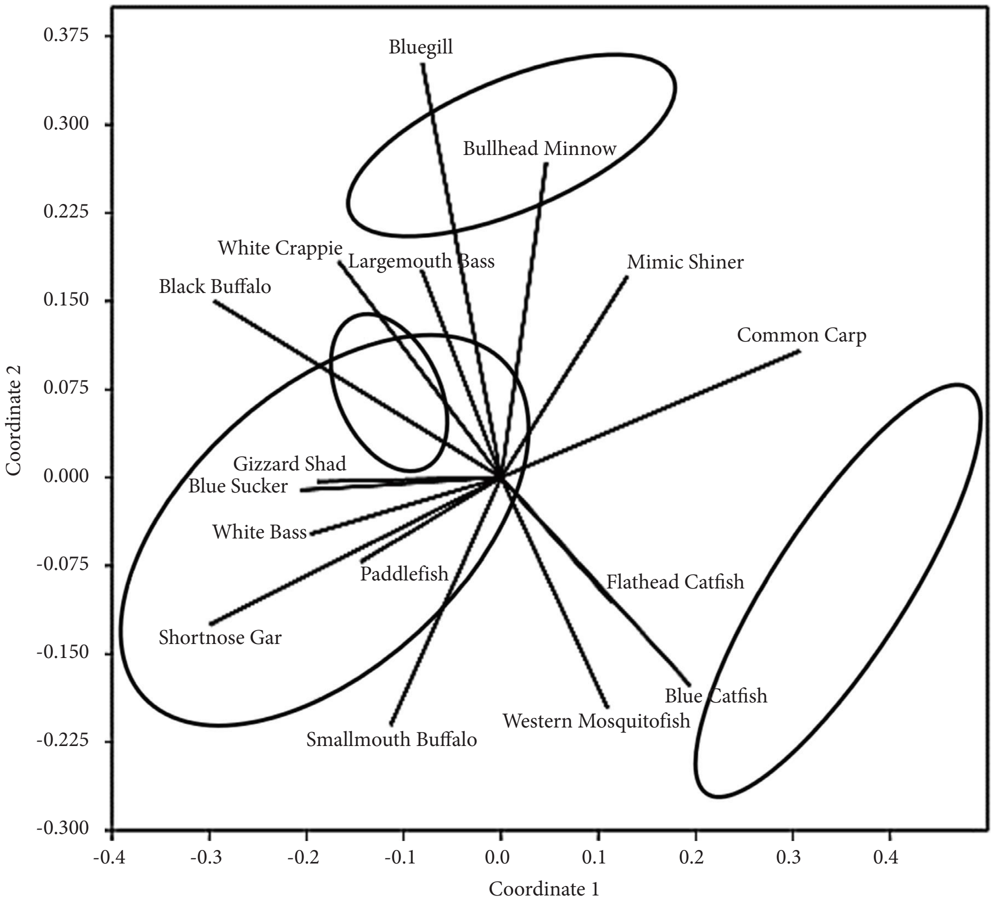

Figure 4: Nonmetric multidimensional scaling (nMDS) analysis with the Bray-Curtis similarity index with calculated multigear mean standardization (MGMS) values for 67 species of fishes from all gears at sampling sites and regions of the Neosho River system (stress = 0.239). Regions are represented by ellipses (i.e., upper Neosho = lower left, middle Neosho = upper middle, lower Neosho = lower right, and Spring river = middle left). Species with higher abundances in specific regions thus contributed to distinct spatial patterns.

results from the Neosho River. Longnose Gar (gill net, mini gill net, hoop net, and modified fyke net) and Bluegill *Lepomis macrochirus* (mini fyke net) were the most encountered species within select respective gears. We also conducted 11.0 hrs (44 runs) of pulsed-DC boat electrofishing on the Spring River and observed 4,517 fishes and 52 species (410.6 (48.3 SE) fish/hr; Table 9). Of these fishes, Gizzard Shad, Smallmouth Buffalo, and Channel Catfish *Ictalurus punctatus* were the most observed. Subsequently, summer sampling resulted in the highest netting catch (i.e., 920 fishes), whereas fall electrofishing produced the highest CPUE (649.9 (99.1 SE) fish/hr).

We encountered 207 fishes (11 species) listed as species in need of conservation (SINC) or threatened and endangered species (T&E) by the state of Kansas [65, 66]; Table 10. Of these, Spotfin Shiner *Cyprinella spiloptera* (0.2), Highfin Carpsucker *Carpiodes velifer* (0.2), and Spotted Sucker *Minytrema melanops* (0.1) were the three most prevalent SINC or T&E fishes in terms of relative abundance (%). Species in need of conservation and T&E fishes constituted 0.7% of the total catch, ranging by sampling location from 0.0% (at both Iola and Humboldt) to 2.2% (at Chetopa and Baxter Springs, with SINC and T&E catch combined and total catch combined for both sites) (Figure 2). We examined SINC and T&E catch at the lowermost dams on each river in Kansas; 159 of 207 SINC and T&E fishes (i.e., 76.8%) were observed in this area. Total observations rose to 187 (i.e., 90.3%) when including the two most downstream dams on each river.

We observed 20 species (including hybrids) and 4,081 total fishes categorized as Kansas sportfish in the Neosho River system. These recreationally important species constituted 14.7% of the total catch (Figure 3). In addition, sportfish percentage of catch at upper and lower sites was 24.2% at John Redmond Dam, 23.1% at Burlington, 5.2% at Neosho Falls, 20.5% at Iola, 18.9% between Oswego and Riverton-Empire Dam (sportfish catch combined and total catch combined for both sites), and 12.1% between Chetopa and Baxter Springs (sportfish catch combined and total catch combined for both sites). Overall, White Bass *Morone chrysops* were the most encountered sportfish (4.0% relative abundance).

We obtained patterns in assemblage of similarity and distinction via nMDS for sites and regions of the Neosho River system based on species' MGMS values (stress = 0.239). The stress value we obtained from nMDS modeling indicates that

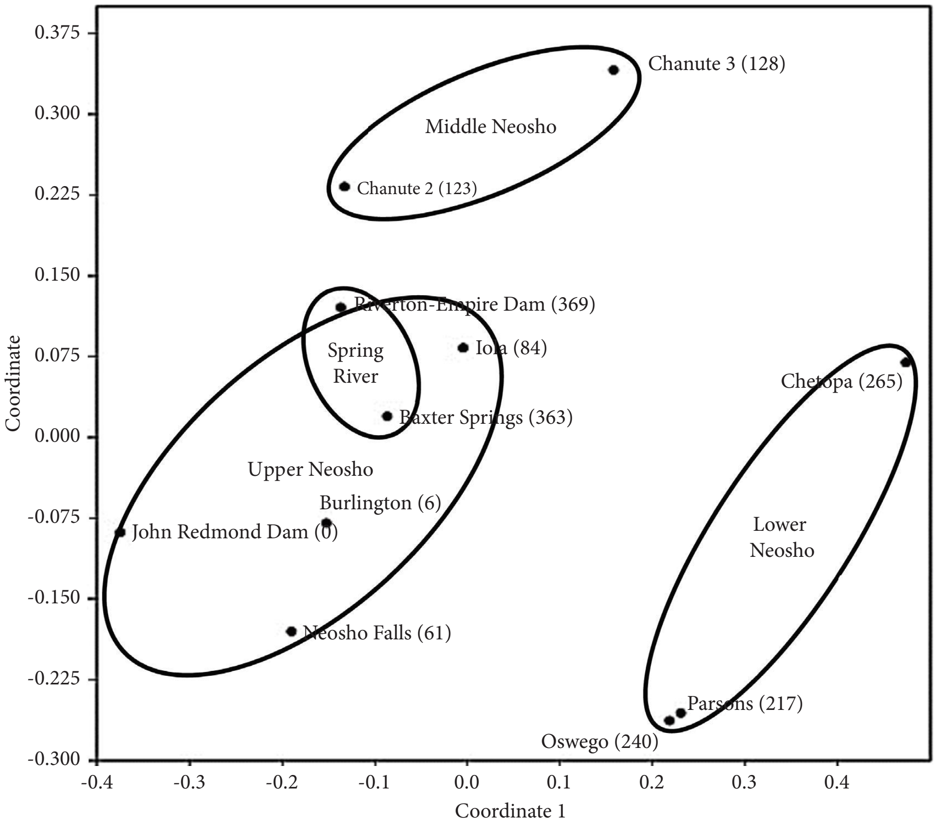

Figure 5: Nonmetric multidimensional scaling (nMDS) analysis with the Bray-Curtis similarity index with calculated multigear mean standardization (MGMS) values for 67 species of fishes from all gears at sampling sites and regions of the Neosho River system (stress = 0.239). River distance in kilometers from John Redmond Dam is displayed in parentheses at each sampling location (i.e., barrier).

the data could be a better fit within the model. However, stress values alone should not determine decipherability of nMDS models [67]. The large number of observations encompassed within the model lends support that a low stress value was unlikely to occur [67]. In addition, each region of the Neosho River system (including the Spring River) separated into unique, mostly isolated clusters via their corresponding sites (Figures 4 and 5). Upper, Middle, and Lower Neosho all were visually identified by nMDS as unique regions from fish assemblage compositions. Species' MGMS values and subsequent distance rankings displayed distinctive upstream and downstream patterns. The Upper Neosho had comparatively higher abundances of Blue Sucker, *Cycleptus elongatus*; Shortnose Gar; and Paddlefish, *Polyodon spathula*; the Middle Neosho had higher abundances of Bluegill; Mimic Shiner, *Notropis volucellus*; and Bullhead Minnow; the Lower Neosho River had greater abundances of Flathead Catfish; Blue Catfish, *Ictalurus furcatus*; Common Carp; and Western Mosquitofish, *Gambusia affinis*; and the Spring River had higher abundances of White Crappie and Largemouth Bass, *Micropterus salmoides*. Black Redhorse, *Moxostoma duquesnei*; Golden Redhorse, *Moxostoma erythrurum*; Bigeye Shiner, *Notropis boops*; Spotfin Shiner; and Highfin Carpsucker also were concentrated in the Spring River. In addition, the Spring River, Upper Neosho, Middle Neosho, and Lower Neosho grouped distinctly within the classical clustering analyses (Figure 6). The cophenetic correlation coefficient associated with this analysis (i.e., 0.85) affirms that the dendrogram validly displays association patterns between sites and regions, expanding on site-by-site similarity or distinction [68]. Classical clustering displayed that the Lower Neosho was the most distinct from Middle and Upper Neosho and the Spring River fell within the Upper Neosho. Chetopa was the most distinct from Parsons and Oswego within Lower Neosho. John Redmond Dam was the most distinct from Burlington within the Upper Neosho. Parsons and Oswego, Chanute 2 and Chanute 3, and Riverton-Empire Dam and Baxter Springs were the most similar sites, respectively. Classical clustering also expanded on nMDS results by defining which sites were most similar outside of regional associations. For example, the fish assemblage at John Redmond was more like Chanute 3 than Lower Neosho sites such as Oswego and Parsons, which was not evident via nMDS.

4. Discussion

Longitudinal differences in the Neosho River system fish assemblages were observed in this study and are likely the result of a combination of natural changes in assemblage with river distance, barrier placement, corresponding hydrologic modifications (e.g., altered flow), and subsequent fragmented interconnectivity [2, 3, 10, 11, 69]. Consequently, modifications may disproportionately influence rare and imperiled fishes that evolved in fluvial unaltered systems [2, 8, 12, 13, 15, 22]. Human activities

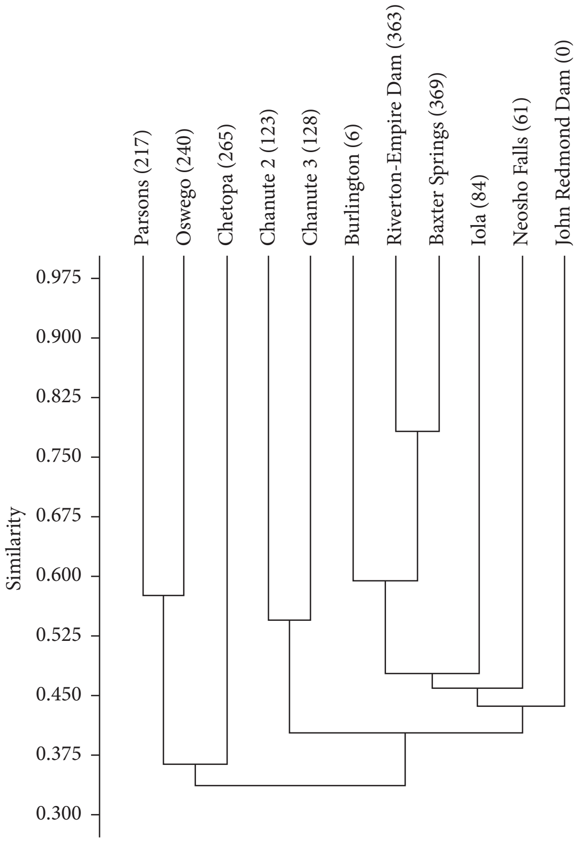

Figure 6: Classical clustering with a paired group (UPGMA) algorithm and the Bray-Curtis similarity index for sampling sites of the Neosho River system performed with calculated multigear mean standardization (MGMS) values for 67 species of fishes from all utilized gears (cophenetic correlation coefficient = 0.85). River distance in kilometers from John Redmond Dam is displayed in parentheses at each sampling location (i.e., barrier).

have homogenized river systems, altered hydrology, reduced habitat abundance, and heterogeneity and in general have caused serial discontinuity in lotic systems [2, 3, 10, 11]. Over 90% of SINC and T&E fishes found below the two most downstream dams on the Neosho River and Spring Rivers could be a product of dams causing serial discontinuity and impeding upstream movement.

Sportfish as defined by KDWP [70] were encountered more frequently at sites near large reservoirs (i.e., John Redmond Reservoir, Grand Lake O' the Cherokees). As such, these reservoirs are likely source populations for piscivorous sportfish populations within those associated river sites. Results from this study suggest that recreationally important piscivorous sportfish are entering the Neosho River system via upstream movement (i.e., Grand Lake O' the Cherokees) and downstream escapement (i.e., John Redmond Reservoir). Specifically, movement of fishes between Oklahoma into Kansas is likely occurring, suggesting interjurisdictional collaboration is necessary [71]. Management of recreationally important species with considerations for native riverine fishes should be prioritized, as sportfish angling in reservoirs and tailwaters provides recreational and economic benefits in North America [20, 72–74]. Previous studies have established that piscivorous sportfish can disrupt native biological communities (e.g., competition and consumption) in lotic environments following reservoir escapement [20]. Our results suggest that sportfish are exhibiting passage from reservoirs into the Neosho River system and, as such, could be disrupting the native biota [20].

A comparatively greater number of SINC and T&E fishes observed at the Spring River suggest that the Spring River may be more suitable for these species than the Neosho River. We also observed greater species richness from the Spring River versus the Neosho River, perhaps suggesting the available habitat (e.g., presence of aquatic vegetation and low turbidity) may better support fish diversity. A higher number of species present at Upper and Lower Neosho versus Middle Neosho could be attributable in part to sportfish presence from reservoir escape as well as SINC and T&E fishes at the most downstream barriers.

Our results suggest that there are both similarities and distinctions in fish assemblages between sites and regions of the Neosho River system. The Spring River, Upper Neosho, Middle Neosho, and Lower Neosho supported unique fish assemblages, indicative of distinctions along a longitudinal gradient. The presence of recreationally important sportfish (e.g., Paddlefish, White Bass, White Crappie, and Ictalurids), SINC and T&E species, small-bodied minnow species, and species found exclusive to a single site pattern dissimilarity between regions. Species responsible for assemblage differences are likely a product of reservoir escapement, subsequent integration, and barrier-induced passage inhibition. In addition, SINC and T&E species and recreationally important reservoir refugees (i.e., sportfish) occupy the same locations throughout the Neosho River system. As such, it is plausible that these reservoir refugees may not be a limiting factor for imperiled species ranges. Methods developed for fish assemblage sampling in this study can be applied to other rivers of interest or continued on this system to obtain a historical fish assemblage dataset. Future studies should investigate SINC and T&E fishes and their potential interactions with reservoir refugee piscivorous sportfish.

Data Availability

The data that support the findings of this study are available from the corresponding author, EJR, upon reasonable request.

Ethical Approval

Approval for research from the Missouri State University Institutional Animal Care and Use Committee was obtained on March 1st, 2021 (IACUC protocol 2020-14).

Disclosure

This manuscript was prepared from the master's thesis "Investigating the Fish Community of the Neosho River System."

Conflicts of Interest

Ben C. Neely is employed by the funding agency for the research associated with this manuscript and is the sole author with potential conflicts of interest.

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