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Research Article

Assessing the invasion history and contemporary diet of nonnative redear sunfish (*Lepomis microlophus* Günther, 1859) in an ecotonal riverscape

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Abstract

The redear sunfish (*Lepomis microlophus* Günther, 1859) is widely-introduced as a sportfish in the United States and globally. The redear sunfish can become invasive when introduced to lentic waterbodies, but the outcome of lotic introductions has received less attention. As such, we evaluated trends in the distribution and abundance of introduced redear sunfish throughout the Spring River subbasin (SRS) of southeastern Kansas during 1962–2019 using five separate datasets. We also examined contemporary diet of the redear sunfish in the SRS during 2018 at sites where it was most abundant to determine if its diet differed from the native range. The SRS included low-velocity, turbid streams draining the Cherokee Lowlands and Osage Cuestas physiographic regions and high-velocity, clear streams flowing through the Ozark Plateau. Streams across all physiographic regions in the SRS are ill-suited to the Redear Sunfish, which prefers low water velocity coupled with high water clarity. We found that the redear sunfish exhibited a restricted distribution with low relative abundance in the SRS throughout the entire study period. Furthermore, its contemporary diet was dominated by non-biting midge larvae (Chironomidae), seed shrimp (Ostracoda), fingernail clams (Sphaeriidae), and snails (Gastropoda), similar to its diet in the native range. The inability of redear sunfish to achieve widespread prevalence in the SRS at least 50 years after introduction likely stems from habitat in the SRS being a poor match to its niche requirements. However, future environmental alterations resulting from human activity and climate change (e.g., dewatering and lentification in streams of the Ozark Plateau) could make conditions in the SRS more suitable for redear sunfish. As such, continued monitoring will be necessary to determine if the prevalence of the redear sunfish in the SRS of Kansas changes in the future.

Key words: distribution, abundance, ontogenetic niche shift, introduced species, sportfish, diet, stream

Introduction

The redear sunfish (*Lepomis microlophus* Günther, 1859) is native to the southeastern United States (Lee et al. 1980; Page and Burr 1991) where it prefers lentic and slow-flowing lotic waterbodies with warm, clear water and abundant aquatic vegetation (Page and Burr 1991; Warren 2009; Tomelleri and Eberle 2011). However, the redear sunfish has been widely introduced for sportfishing purposes into regions to the north and west of its range in the USA (Whittier and Hartel 1997; Huckins et al. 2000; Fuller et al. 2014). Furthermore, the redear sunfish has been introduced on a global scale, with introductions reported from Mexico, Morocco, Panama, Puerto Rico, and the Virgin Islands (Froese and Pauly 2018). In the native range the diet of redear sunfish is dominated by benthic invertebrates, including clams, small mussels, aquatic snails, amphipods, small aquatic insects (e.g., midge larvae), and large aquatic insects (e.g., dragonfly nymphs) (Peterson et al. 2006; Warren 2009). Furthermore, redear sunfish exhibit ontogenetic diet shifts, feeding on small crustaceans and insects when smaller, then switching to progressively larger prey (e.g., snails, clams, and insects) with increases in body size (Huckins 1997; Huckins et al. 2000; Peterson et al. 2006; Warren 2009).

The redear sunfish is a documented invasive species under some environmental conditions. The redear sunfish can become invasive when introduced into lentic habitats, as it reduces native snail populations via predation, and outcompetes native molluscivorous fish (Huckins et al. 2000). However, the outcome of redear sunfish introductions in flowing-water environments has received less attention, and as such it remains unclear if they could also become invasive in rivers and streams. Redear sunfish are typically less abundant in lotic habitats compared to adjacent lentic habitats (Beecher et al. 1977; Rutherford et al. 2001; Warren 2009), but that does not mean redear sunfish do not possess the ability become invasive in flowing-water environments. Long-term changes in redear sunfish prevalence and their dietary patterns should be assessed in novel lotic ecosystems across a broad range of physicochemical conditions (i.e., water clarity, velocity, etc.) to gain further insight about the outcome of redear sunfish introductions in flowing-water environments. Given the habitat preferences of the redear sunfish, the highest potential for successful establishment and spread following introduction is predicted for clear, slow-flowing streams, while introductions may be less successful or fail entirely in streams that are faster-flowing and/or more turbid. Testing these predictions has important management implications, as it could be used to help forecast the outcome of redear sunfish introductions in novel riverscapes.

The first objective of our research was to evaluate the invasion history of introduced redear sunfish in a riverscape that provided a wide-range of physicochemical habitat conditions because of its ecotonal nature. We addressed this objective by examining trends in the distribution and abundance of the redear sunfish in an ecotonal riverscape over a 57-year time period. Our second objective was to quantify the contemporary diet of introduced redear sunfish in our study area to evaluate if dietary patterns in a novel riverscape differed from the diet reported in the native range. The redear sunfish has been widely introduced across the United States and globally, thus our results could inform the management of redear sunfish

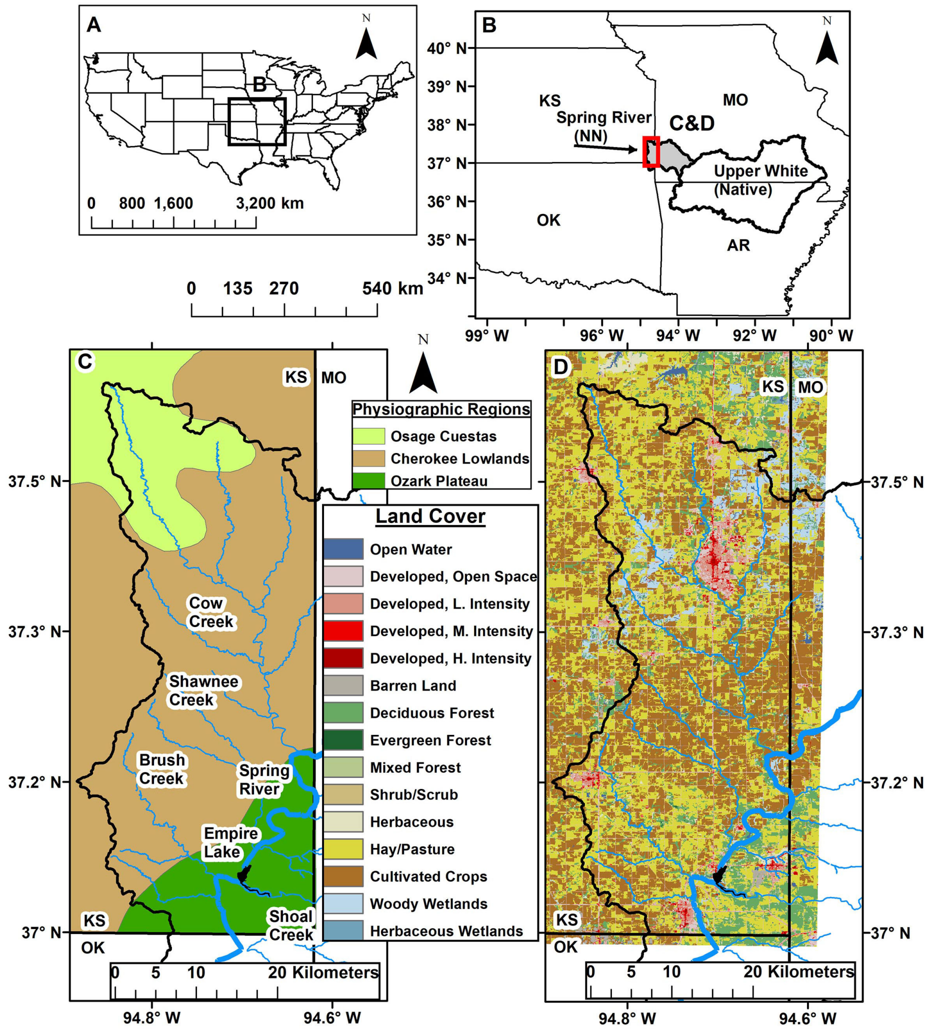

Figure 1. Maps depicting physiographic regions and land cover and use in the Spring River subbasin (SRS) of Kansas (KS). The redear sunfish (*Lepomis microlophus*) is nonnative (NN) in the SRS of KS, but is native in the adjacent Upper White River basin. A, United States; B, Four-State Area; C, Physiographic regions of the SRS of KS (Aber and Aber 2009); D, land cover and land use in the SRS of KS (Homer et al. 2015).

in other parts of its introduced range, especially in stream ecosystems where little is known concerning the outcome of introductions.

Materials and methods

Our study was conducted in the Spring River subbasin (SRS) of southeastern Kansas (KS), USA (Figure 1). The redear sunfish is nonnative throughout KS (Tiemann 2014), but has been intentionally stocked in small impoundments and larger reservoirs as a sport fish. Some of these stocked redear sunfish have escaped from lentic waterbodies into rivers and streams (Tiemann 2014) by swimming upstream from reservoirs, by moving downstream during overflow and inundation events following heavy precipitation, or via exiting through spillways (Gido et al. 2004; Gozlan et al. 2010; Perkin et al. 2014). The redear sunfish was likely introduced to the SRS of KS via one or more of these introduction pathways, although the specific mode of introduction is unknown. The SRS is adjacent to the White River basin where redear sunfish are native (Figure 1), so introduced redear sunfish in the SRS are not far from their native range (Lee et al. 1980; Page and Burr 1991). All lentic waterbodies where redear sunfish have been stocked in the SRS are artificial, and include the numerous strip pit lakes that are a legacy of surface coal mining, and Empire Lake, which is a small power plant cooling reservoir formed by an impoundment near the confluence of Shoal Creek and Spring River (Figure 1).

The SRS of Kansas represents an ecotonal riverscape. Specifically, the Spring River mainstem bisects the subbasin from the low-relief Osage Cuestas and Cherokee Lowlands to the west and north from the higher-relief Ozark Plateau to the east and south (Figure 1; Wilkinson and Edds 2001; Aber and Aber 2009). The boundary formed by the Spring River mainstem ultimately contributes to separating the Great Plains from the Eastern Temperate Forests (Omernik 1987). Historically tallgrass prairie dominated the Osage Cuestas and Cherokee Lowlands (Küchler 1974), but nearly all of this tallgrass prairie has been converted to agriculture (76% of watershed) or developed land (10% of watershed) (Figure 1; Homer et al. 2015). Deciduous forest was historically the major land cover in the Ozark Plateau, and although urbanization (13% of watershed) and agriculture (54% of watershed) have reduced its prevalence, it continues to be a major land cover type (30% of watershed), and is much more prevalent compared to the Osage Cuestas and Cherokee Lowlands (8% forested) (Figure 1; Homer et al. 2015). Tributaries draining the Osage Cuestas and Cherokee Lowlands tend to be turbid, slow-flowing, silty, and intermittent, whereas tributaries flowing from the Ozark Plateau are generally clearer, faster-flowing, rocky, and more perennial (Davis and Schumacher 1992; Wilkinson and Edds 2001). Furthermore, tributaries draining the Ozark Plateau have elevated levels of cadmium, lead, and zinc from a legacy of lead and zinc mining (Wildhaber et al. 2000; Chambers et al. 2005; Angelo et al. 2007), although metal concentrations in these streams have greatly decreased over the last decade (Boroughs 2020). Because the redear sunfish prefers clear, slow-flowing water, we predicted limited success of redear sunfish introductions throughout the SRS of KS, as Osage Cuestas and Cherokee Lowland streams would be too turbid, and Ozark Plateau streams would be flowing too swiftly to support widespread and abundant populations.

We used five separate datasets to evaluate changes in prevalence of the redear sunfish in the SRS of KS over time, including 1) Branson et al. (1969), 2) Silovsky and Triplett (1991), 3) Wilkinson and Edds (2001), 4), the Kansas Department of Wildlife, Parks, and Tourism (KDWPT) stream assessment and monitoring program database (SAMP; obtained from Ryan Waters, KDWPT), and 5) our own contemporary survey (Figure 2; Table 1). Most studies included a mixture of sites from the Ozark Plateau and Cherokee Lowlands+Osage Cuestas, although the 1983–1984 survey only had Ozarkian sites (Figure 2). All studies relied on a combination of electrofishing and

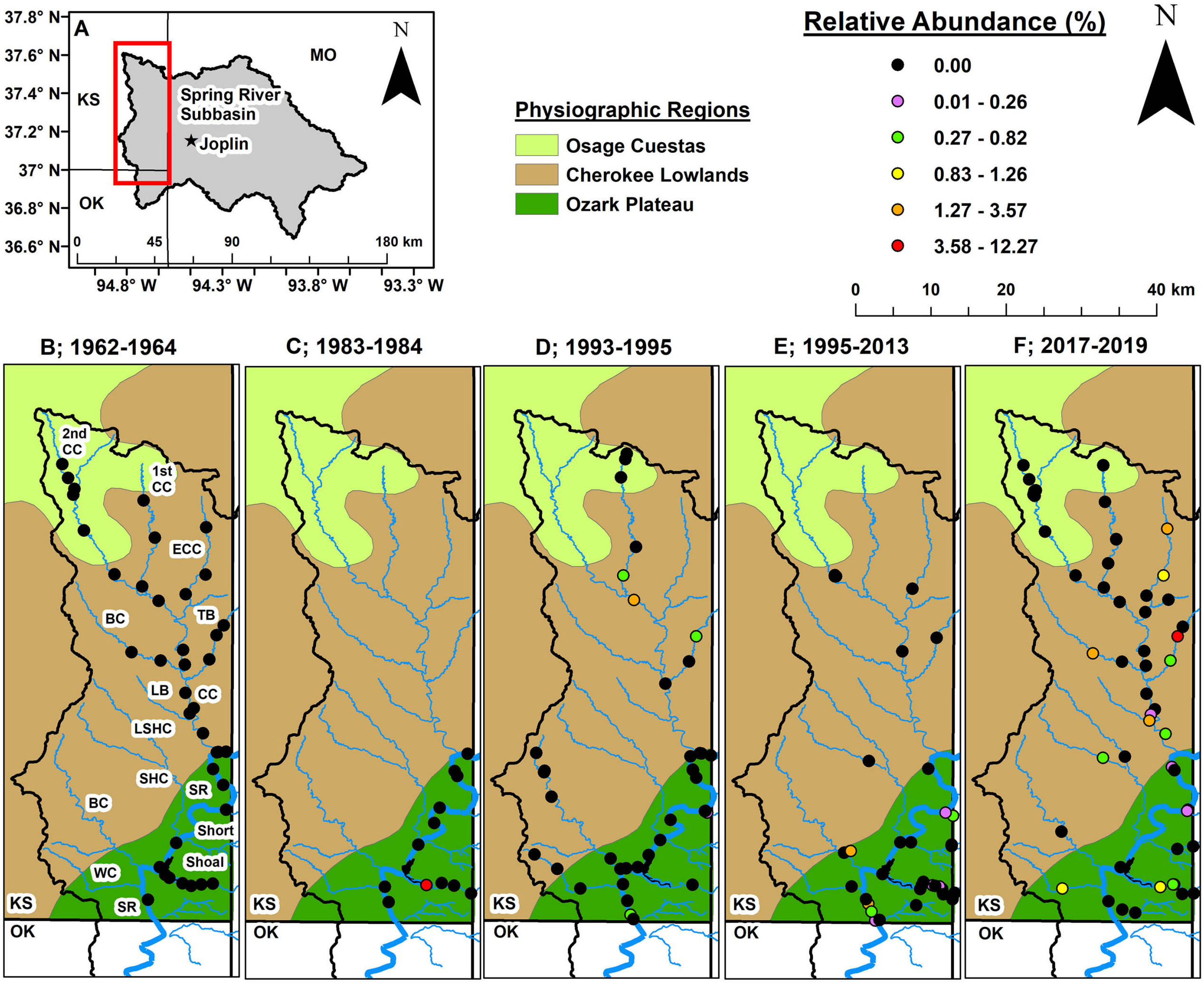

Figure 2. Site-level relative abundance of the nonnative redear sunfish (*Lepomis microlophus*) in the Spring River subbasin of Kansas across five datasets. See Table 1 for further information on dataset attributes. 2ndCC = Second Cow Creek; 1stCC = First Cow Creek; BC = Brush Creek (there are two separate Brush Creeks); CC = Cow Creek; ECC = East Cow Creek; LB = Long Branch; LSHC = Little Shawnee Creek; SHC = Shawnee Creek; Shoal = Shoal Creek; Short = Short Creek; SR = Spring River; TB = Taylor Branch; WC = Willow Creek. A, Spring River subbasin; B, Branson et al. (1969) dataset; C, Silovsky and Triplett (1991) dataset; D, Wilkinson and Edds (2001) dataset; E, Kansas Department of Wildlife, Parks and Tourism dataset; F, contemporary dataset.

Table 1. Attributes of the five datasets used to assess changes in prevalence of the nonnative redear sunfish (*Lepomis microlophus*; LEPMIC) in the Spring River subbasin of Kansas. Rank = rank abundance ranked from highest to lowest relative abundance across all fishes detected in a dataset. KDWPT SAMP = Kansas Department of Wildlife, Parks and Tourism Stream Assessment and Monitoring Program.

Dataset	Time Period	Total Sites	LEPMIC Sites	Total Fish	Total LEPMIC	LEPMIC Rank
Branson et al. (1969)	1962–1964	39	0	10,501	0	–/77
Silovsky and Triplett (1991)	1983–1984	14	3	3,963	9	38/61
Wilkinson and Edds (2001)	1993–1995	43	6	14,104	11	55/72
KDWPT SAMP	1995–2013	40	9	34,737	33	58/81
Contemporary	2017–2019	53	14	24,737	83	25/72
Grand Total	1962–2019	189	32	88,042	136	54/88

seining to evaluate fish community structure at sample sites, excluding Wilkinson and Edds (2001) that only used seining. To assess the prevalence of the redear sunfish in each dataset, we calculated their naïve occupancy (i.e., number of sites where redear sunfish was detected divided by the total number of sample sites) and relative abundance (i.e., number of redear

Table 2. Sites where the nonnative redear sunfish (*Lepomis microlophus*) were collected for diet analysis during August–September 2018, including the mean and range of total length (TL) for those individuals. Sites are arranged in alphabetical order; n = sample size (i.e., number of individuals collected at a site for diet analysis); CR = Crawford County; CK = Cherokee County.

Site	Diet (n)	TL (range) (mm)	Latitude decimal	Longitude decimal
East Cow Creek	2	111 (111–111)	37.4677	−94.6499
Long Branch	2	140 (140–140)	37.2379	−94.6722
Shawnee Creek	9	127 (96–157)	37.1977	−94.7405
Taylor Branch (CR)	27	126 (94–159)	37.3390	−94.6380
Taylor Branch (CK)	2	85 (78–91)	37.3094	−94.6467
Willow Creek	24	77 (32–150)	37.0374	−94.7759
Total	66	107 (32–159)		

sunfish individuals captured divided by the total number of individuals captured across all species), and then multiplied these proportions by 100 to convert them to percentages. Occupancy and relative abundance were calculated for the entire SRS, and were also calculated separately for the Ozark Plateau versus the Cherokee Lowlands and Osage Cuestas combined. Finally, in addition to calculating redear sunfish relative abundance across all sites within a dataset, we also calculated it at the site level within datasets and then plotted values on distribution maps to visualize areas with the largest relative abundances.

To assess the diet of redear sunfish, we collected individuals for gut contents analysis during August–September 2018 at six sites, which corresponded to the six sites where redear sunfish were found to be most abundant during 2017–2019 (Table 2). Fish were collected using backpack electrofishing and seining, and were then fixed in 10% formalin on site directly following collection. In the lab the total length (mm) of each individual was recorded, then the gastrointestinal tract from the esophagus to the second bend of the intestine was extracted and dissected (Chipps and Garvey 2007; Alexander and Perkin 2013). Gut contents were inspected and identified under a dissecting microscope. Each diet item was identified to the lowest practical taxonomic level. We assigned diet items from one to three taxonomic levels, depending on the degree of digestion. From coarsest to finest those levels were: category (typically phylum), subcategory (typically class), and taxon (typically order or family). The presence/absence of diet items was recorded for each individual to provide percent occurrence for each diet item across individuals, which provided a robust and interpretable measure of diet composition (Baker et al. 2014).

We used generalized linear mixed effects models to evaluate the relationship between body size (i.e., total length; fixed effect) and the probability of occurrence of diet items (response variable) while including "site" as a random effect. We treated "site" as a random effect because sample sizes and mean body lengths varied among our sites where we collected individuals for diet analysis (Table 2). We created models for five separate diet items, including Crustacea, aquatic Insecta, Bivalvia, Gastropoda, and amorphous detritus (Table 3). These categories were selected because

Table 3. Percent occurrence (Occur.) of diet items found in the gut contents of the nonnative redear sunfish (*Lepomis microlophus*) collected from six locations in the Spring River subbasin of Kansas during August–September 2018. Gut contents from 66 total individuals (Ind.) were analyzed (see Table 2 for further details). The mean and range of total length (TL) of individuals containing particular diet items are also indicated.

Category	Subcategory	Taxon	Ind. #	Occur. %	TL (range) (mm)
Aquatic Arthropod			58	87.9	109 (32–159)
	Crustacea			22.7	66 (32–159)
		Amphipoda	1	1.5	110
		Decapoda	1	1.5	139
		Ostracoda	13	19.7	57 (32–70)
	Insecta			74.2	118 (56–159)
		Anisoptera nymph	2	3.0	122 (120–123)
		Chironomide larvae	49	74.2	118 (56–159)
		Corixidae	2	3.0	118 (91–145)
		Ephemeroptera nymph	3	4.5	126 (110–159)
		Haliplidae larvae	1	1.5	128
		Tabanidae larvae	1	1.5	159
		Unidentified insects	4	6.1	114 (110–120)
Aquatic Mollusk			48	72.7	116 (54–159)
	Bivalvia			34.8	124 (56–157)
		Unidentified Bivalvia	3	4.5	137 (120–157)
		Corbiculidae	4	6.1	144 (140–146)
		Sphaeriidae	20	30.3	123 (56–157)
	Gastropoda		19	28.8	115 (56–152)
	Shell fragments		43	65.2	118 (54–159)
Amorphous Detritus			44	66.7	111 (37–159)
Filamentous Algae			13	19.7	130 (78–159)
Terrestrial Arthropod	Insecta		3	4.5	143 (137–152)
		Formicidae	1	1.5	152
		Orthoptera	1	1.5	152
		Coleoptera	1	1.5	137
		Unidentified insect	1	1.5	140
Nematomorpha			2	3.0	135 (110–159)

they were the only ones common enough across individuals to perform statistical analyses. All statistical analyses were conducted in program R version 4.0.3 (R Core Team 2020). Our models were created with a binomial distribution and logit link (McCullagh and Nelder 1989; Crawley 2005) as implemented in the glmer function from the lme4 package (Bates et al. 2015). To assess the overall significance ($\alpha = 0.05$) and explanatory power of each model, we relied on a likelihood ratio test (anova function, R base package; R Core Team 2020) and pseudo r^2 (r.squaredGLMM function, MuMIn library; Barton 2020), respectively. We used the delta method to calculate the marginal (i.e., variance explained by the fixed effect only) pseudo r^2 (Barton 2020). Significant relationships between body size and occurrence of diet items would be evidence for ontogenetic shifts in diet.

Results

The redear sunfish maintained a restricted distribution with low abundance throughout the SRS of KS during 1962–2019 (Figures 2, 3; Table 1). The redear sunfish was not detected in the SRS of KS during the 1962–1964 survey, although one individual was found within Shoal Creek in Missouri in 1962, and two and four individuals were found in Lost and

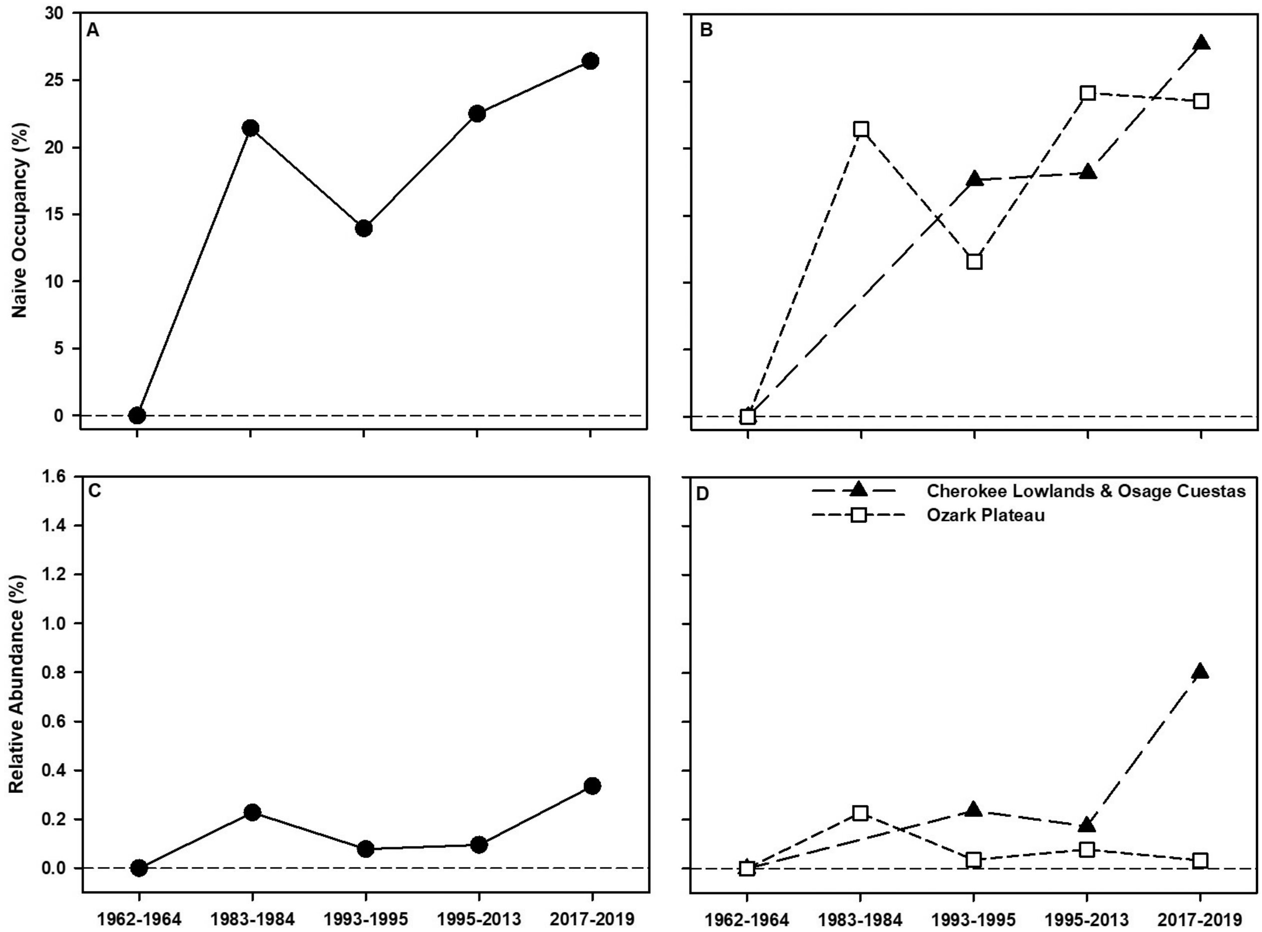

Figure 3. Trends in naïve occupancy and relative abundance of the nonnative redear sunfish (*Lepomis microlophus*) in the Spring River subbasin (SRS) of Kansas across five time periods. Trends are presented for the SRS as a whole, and for separate physiographic regions with the SRS. A, naïve occupancy in the SRS; B, naïve occupancy in the Ozark Plateau versus the Cherokee Lowlands and Osage Cuestas within the SRS; C, relative abundance in the SRS; D, relative abundance in the Ozark Plateau versus the Cherokee Lowlands and Osage Cuestas within the SRS.

Sycamore Creeks, respectively, in Oklahoma in 1964 (Branson et al. 1969). Redear sunfish was first detected in the KS SRS within Shoal Creek just upstream from Empire Lake during 1970–1971 (Kansas Fishes Committee 2014), although these records were not included among our five datasets. Among our five datasets the redear sunfish was first detected in the SRS of KS in Shoal Creek during the 1983–1984 survey, but since then their occupancy and relative abundance have remained fairly stable, with occupancy hovering around 15–25% of sample sites, and relative abundance across entire datasets much lower at ≤ 0.34% (Figure 3). Excluding 1962–1964, redear sunfish were rarest during 1993–1995, and achieved their greatest prevalence during 2017–2019. Furthermore, redear sunfish had similar occupancy and relative abundance over time in the Ozark Plateau compared to the Cherokee Lowlands+Osage Cuestas, although during 2017–2019 relative abundance was much greater in the Cherokee Lowlands+Osage Cuestas versus the Ozark Plateau (Figure 3). Redear sunfish were most abundant in small tributary streams draining the Cherokee Lowlands, but could also be abundant where Shoal Creek, an Ozarkian stream, entered Empire Lake (Figure 2). Within these streams redear sunfish relative abundance could approach ~ 12% of individuals within a sample site (Figure 2). Otherwise, redear sunfish were rare at sample sites in the KS SRS.

We collected 66 total redear sunfish for diet analysis across the six sites, although most (51; 77%) of these individuals came from just two sites (Taylor Branch in Crawford County and Willow Creek; Table 2). Because of this limitation it was difficult to discern any variation in diet among sites, so we only focused on diet patterns at the subbasin scale. The mean length of individuals collected for diet was 107 mm (range = 32–159 mm), which was similar to the size range we observed for the 83 individuals we collected during 2017–2019 when we performed fish community sampling (mean = 103 mm; range = 62–171 mm) (Tables 1, 2). As such, our sample of individuals for diet should be representative of the body sizes that are typical of redear sunfish in the SRS.

A variety of macroinvertebrate prey items were found in the gut contents of the redear sunfish (Table 3). The redear sunfish diet consisted of 22 diet items falling into six categories, with aquatic arthropods (87.9% occurrence), mollusks (72.7%) and amorphous detritus (66.7%) being common across all individuals, whereas filamentous algae (19.7%), terrestrial arthropods (4.5%), and Nematomorpha (3.0%) were rarer. The dominant aquatic arthropods in gut contents were non-biting midge larvae (74.2%; class Insecta; order Diptera; family Chironomidae) and seed shrimp (19.7%; subphylum Crustacea, class Ostracoda). Among mollusk diet items fingernail clams (30.3%; class Bivalvia; order Veneroida; family Sphaeriidae) and snails (28.8%; class Gastropoda) were similarly common, with the nonnative Asian Clam (*Corbicula fluminea* Müller, 1774) found in a small (i.e., 6.1%) number of individuals.

The redear sunfish exhibited ontogenetic diet shifts. Specifically, the probability of Crustacea occurring in gut contents was inversely related to body size ($\chi^2 = 10.4$; degrees of freedom [df] = 63; $p = 0.001$; pseudo $r^2 = 0.27$; Figure 4). This pattern was largely driven by the presence of Ostracoda (seed shrimp) in the gut contents of many smaller redear sunfish (Table 3). Furthermore, the probability of occurrence of aquatic Insecta ($\chi^2 = 5.7$; df = 63; $p = 0.017$; pseudo $r^2 = 0.13$) and Bivalvia ($\chi^2 = 18.5$; df = 63; $p < 0.001$; pseudo $r^2 = 0.39$) in gut contents increased with body size. The presence of non-chironomid insects (e.g., dragonfly and mayfly nymphs) and Asian Clam in larger redear sunfish were responsible for the pattern in aquatic Insecta and Bivalvia, respectively. Finally, the probability of occurrence of Gastropoda ($\chi^2 = 2.4$; df = 63; $p = 0.12$; pseudo $r^2 = 0.06$) and amorphous detritus ($\chi^2 = 1.8$; df = 63; $p = 0.18$; pseudo $r^2 = 0.03$) did not vary with body size (Figure 4).

Discussion

Our study indicated minimal success of introduced redear sunfish in an ecotonal riverscape, as their distribution and abundance remained low across

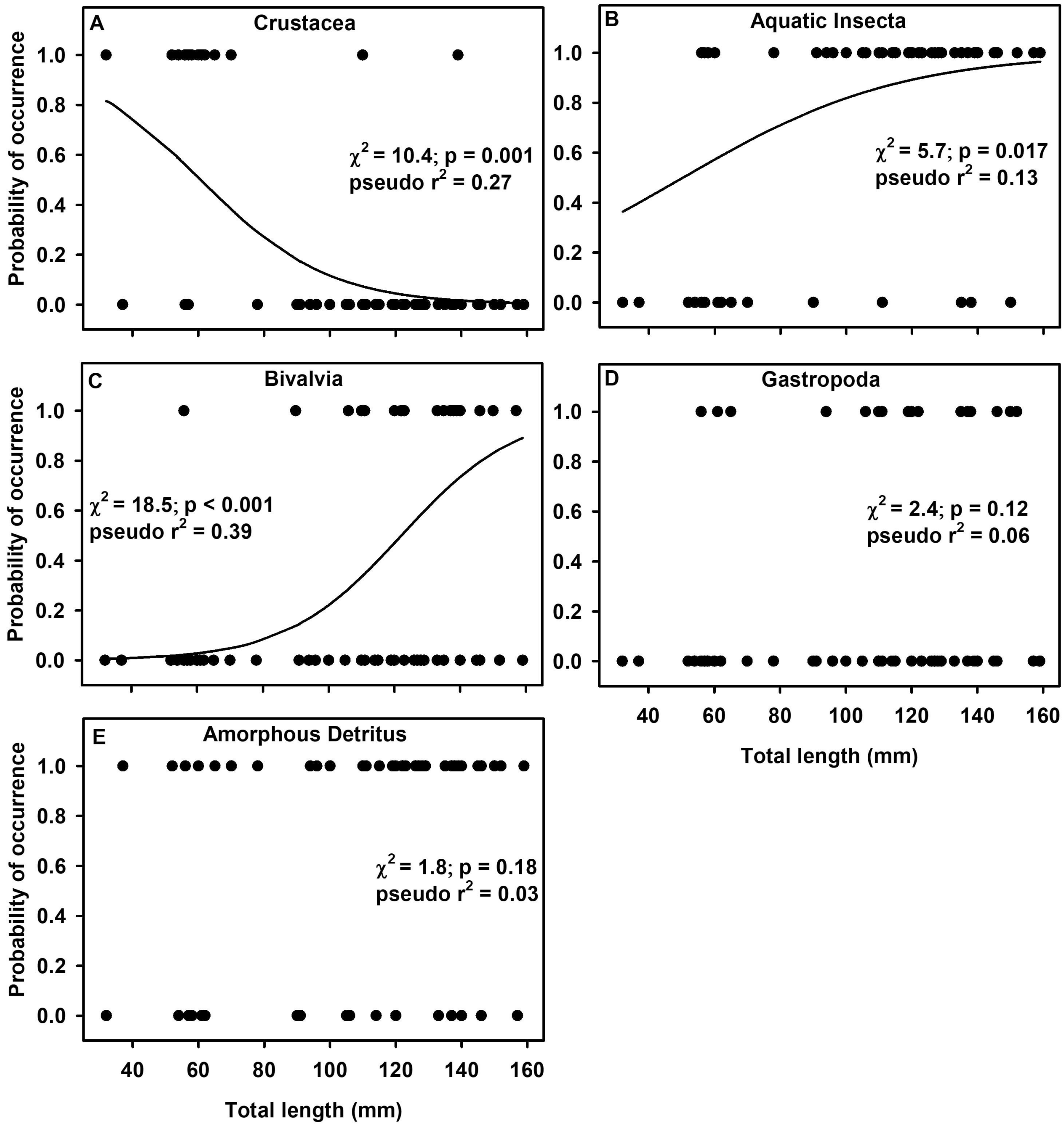

Figure 4. Probability of occurrence of five diet items with changes in body size in the nonnative redear sunfish (*Lepomis microlophus*) in the Spring River subbasin of Kansas. Degrees of freedom for all regressions were 63. A, Crustacea; B, Aquatic Insecta; C, Bivalvia; D, Gastropoda; E, Amorphous Detritus.

a 57-year time period in the SRS of KS. The first appearance of the redear sunfish in the KS SRS was in Shoal Creek just upstream from Empire Lake (Kansas Fishes Committee 2014), which points to a stocking in Empire Lake as the potential mode of first introduction. However, it is also possible that individuals from Shoal Creek in Missouri dispersed downstream to Kansas, as redear sunfish were present in Shoal Creek upstream in Missouri by 1962 (Branson et al. 1969). Furthermore, there has likely been numerous introductions of redear sunfish throughout the KS SRS for sportfishing purposes since the initial populations were introduced to

Shoal Creek during the 1960s–1970s. Regardless, the inability of the redear sunfish to become widespread and abundant in the KS SRS over a > 50-year time period was likely a consequence of inadequate habitat availability relative to niche requirements. The redear sunfish prefers lentic or slow-flowing lotic habitat with clear water (Tiemann 2014), which is generally unavailable in the KS SRS as streams are either slow-flowing and turbid (Cherokee Lowlands and Osage Cuestas) or fast-flowing and clear (Ozark Plateau). The redear sunfish was most abundant in the small tributaries draining the Cherokee Lowlands (Figures 2, 3), which are turbid as a consequence of their watersheds being heavily-impacted by agriculture (Figure 1; Davis and Schumacher 1992; Chambers et al. 2005; Homer et al. 2015; Whitney et al. 2019). The turbid water may impair sight-feeding activity of redear sunfish in these small streams, ultimately limiting population size and growth by hampering food acquisition. Miranda and Lucas (2004) found the redear sunfish to be less abundant in turbid floodplain lakes of the Mississippi River valley compared to those that were clearer, highlighting the redear sunfish's preference for clear water. However, Cherokee Lowland streams are intermittent and have low flow, which may provide the semi-lentic conditions redear sunfish prefer. The clearest streams in the SRS of KS are those draining the Ozark Plateau, but the higher velocity of these streams (Davis and Schumacher 1992) may restrict redear sunfish from occurring in these strongly-lotic habitats, except near Shoal Creek's confluence with Empire Lake where water velocity slows. We acknowledge that a lag response (Crooks 2005; Richardson and Pysek 2006) or insufficient time to spread (Vander Zanden and Olden 2008; Strayer 2010) could explain the inability of redear sunfish to become widespread and abundant in the KS SRS, although we think this is unlikely since the redear sunfish has a short generation time (i.e., age at maturity = 1–2 years; Tiemann 2014) and has been present in the SRS of KS since at least 1970. Finally, even though the redear sunfish was a relatively rare component of the SRS fish assemblage, its relative abundance did increase within the Cherokee Lowlands during 2017–2019 (Figures 2, 3). Further monitoring is necessary to determine if this is the beginning of a long-term trend of increasing relative abundance, or instead is just short-term variation.

The diet of nonnative redear sunfish in the SRS of KS was similar to its diet reported from the native range. First, the major macroinvertebrate diet items of the redear sunfish in the KS SRS included chironomids, fingernail clams, and snails (Table 3). Furthermore, nonnative redear sunfish in the KS SRS exhibited an ontogenetic shift in diet, switching from ostracods when smaller to larger insects and bivalves with increases in body size. Both of these dietary attributes were consistent with the diet of the redear sunfish in its native range (Peterson et al. 2006; Warren 2009; Tiemann 2014). It is worth mentioning that the SRS of KS is home to many imperiled fishes and Unionid mussels (Couch 1997; Kansas Fishes Committee 2014), but it does not appear that these imperiled species are part of the redear sunfish's diet. For instance, there were no fish prey present in the diet of the redear sunfish, although there were unidentifiable shell fragments and bivalves that could have been juveniles of imperiled Unionid mussels. However, imperiled Unionid mussels in the SRS prefer larger, perennial streams and rivers (e.g., Spring River) where the redear sunfish was rare (Figure 2; Branson 1966; Couch 1997; Angelo et al. 2007). As such, the likelihood of the redear sunfish actively consuming many imperiled Unionid mussels is low given their complementary distributions in our study system. However, we note that we had a relatively small sample size (i.e., n = 66) for our diet analysis that was limited by the rarity of redear sunfish in the SRS of KS, and we only assessed redear sunfish diet during late summer. If there is seasonal variation in diet, redear sunfish may be consuming imperiled unionids or other aquatic organisms that differ from their known diet during other parts of the year. As such, future studies should collect more redear sunfish and examine seasonal changes in diet to address our study's limitations.

Our finding of limited introduction success for redear sunfish differed from the conclusions of Huckins et al. (2000), who found high introduction success of redear sunfish in southern Michigan lakes, ultimately causing the species to become invasive (i.e., having negative effects on recipient ecosystems; Kolar et al. 2010). Specifically, redear sunfish predation decreased snail populations in lakes where they were introduced, which ultimately decreased pumpkinseed sunfish (*Lepomis gibbosus* Linnaeus, 1758) abundance via competition, since their main prey was also snails (Huckins et al. 2000). Differences in the conclusions concerning introduction success between our study and Huckins et al. (2000) likely arose from redear sunfish being introduced into their preferred lentic habitat that allowed them to achieve high population densities in Huckins et al. (2000), but instead were in lotic habitat in our study, which likely diminished their ability to spread and multiply. Furthermore, the closely-related (Mabee 1993; Warren 1999) and functionally similar (i.e., specialized molluscivore; Mittelbach 1984; Huckins 1997) pumpkinseed sunfish was native in Huckins et al. (2000), but does not occur in the SRS. Our results combined with those of Huckins et al. (2000) suggested the potential for successful establishment, spread, and concomitant invasive impacts of redear sunfish might be greater in lentic compared to lotic waterbodies, although slow-flowing streams with clear water could provide ideal conditions that allow redear sunfish to become invasive.

By examining the invasion history of nonnative redear sunfish in the SRS of KS, we found that its prevalence remained relatively low and stable over a 57-year time period. However, ongoing environmental change in the SRS could eventually allow for greater prevalence of redear sunfish. For example, the Joplin, MO metropolitan area is located within the SRS

(Figure 2) and is growing rapidly, and this population growth coupled with drought are projected to result in water shortages in the region as early as 2030 (CDM Smith 2014). Greater water demand in Joplin and elsewhere in the SRS could result in dewatering and lentification of clear, Ozarkian streams (Sabater 2008; Ruhí et al. 2015), making conditions more suitable for the redear sunfish. To meet the growing water demand, plans are underway to construct an off-channel storage reservoir on a Shoal Creek tributary in Missouri (i.e., Baynham Branch) which would be filled by diverting high flows from Shoal Creek, and via an interbasin water transfer (i.e., from Stockton Reservoir in the Sac River subbasin to the north). This new reservoir could make conditions in Shoal Creek more suitable for redear sunfish by decreasing flows, and could also provide an additional source population that could supply redear sunfish propagules. Finally, increasing temperatures and evapotranspiration associated with climate change could exacerbate dewatering resulting from greater human water usage (Wang and Hejazi 2011), further facilitating the spread of redear sunfish by creating more favorable habitat (Frederick and Gleick 1999; Rahel and Olden 2008; Pandit et al. 2017). Continued monitoring of distribution, abundance, and diet will help reveal if the introduction success of the redear sunfish in the SRS changes into the future.

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