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Collapsing Range of an Endemic Great Plains Minnow, Peppered Chub Macrhybopsis tetranema

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Abstract—The Peppered Chub *Macrhybopsis tetranema* was once found throughout the Arkansas River basin in portions of Texas, New Mexico, Oklahoma, Kansas, and Colorado. Range-wide declines in both abundance and distribution have occurred over the past three decades coinciding with habitat loss and fragmentation. Over the last decade or more, only two geographically isolated Peppered Chub populations persisted in the Arkansas and Ninnescah rivers in Kansas and a portion of the Canadian River in New Mexico and Texas. Intensive sampling between 2011 and 2013 documented the decline of this species from Kansas during consecutive years of region-wide drought in 2011 and 2012. Equally intensive sampling in 2015 in reaches of the Ninnescah and Arkansas rivers yielded no individuals, suggesting the potential extirpation of this population. Conversely, Peppered Chub were consistently collected in the Canadian River in New Mexico from 2012 to 2015 with increasing numbers in recent years with higher flows. Therefore, Peppered Chub is either extirpated or has declined below detection in Kansas and a stable population only remains in a 220 km reach of the Canadian River. A recovery plan for the Peppered Chub might consider restoration and maintenance of adequate seasonal fluctuating river flows, removal of barriers, and repatriation to river reaches that have experienced extirpation.

Introduction

Combined effects of drought and fragmentation has led to declines in fish biodiversity across the Great Plains (Perkin *et al.*, 2015a). Perkin *et al.* (2015b) proposed an "ecological ratchet" for the Arkansas and Ninnescah rivers in Kansas in which several species that declined following moderate to severe droughts (*i.e.*, Palmer Drought Severity Index values < -2 and -3, respectively) were not able to recover because of a highly fragmented river system. They hypothesized this ratcheting mechanism likely first began in the 1960s following reservoir and small-dam construction, fragmenting both rivers and exacerbating the effects of drought on population dynamics of pelagic-spawning minnows (*i.e.*, Arkansas River Shiner *Notropis girardi*, Plains Minnow *Hybognathus placitus*, and Peppered Chub

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Macrhybopsis tetranema). There exist several examples where drought in concert with fragmentation may have led to a ratcheting down of other members of this pelagic-spawning reproductive guild, specifically members of the genus *Macrhybopsis*, across the Great Plains. Kelsch (1994) failed to collect Sturgeon Chub *M. gelida* in a fragmented reach of the Little Missouri River, North Dakota following a 6 y drought despite the species being common in historical samples. Burrhead Chub *M. marconis* experienced declines and extirpation following a 10 y period of drought in south Texas due to consecutive failed reproductive efforts (Perkin *et al.*, 2013). Perkin *et al.* (2013) hypothesized impoundments blocked the recolonization of upstream reaches despite the return of flows, therefore leading to Burrhead Chub extirpation. Recent sampling efforts in the Arkansas River, Kansas showed declines in the probability of occurrence of Peppered Chub from 0.35 ± 0.15 (mean ± 95% confidence interval) in 2000–2008 to 0.06 ± 0.03 in 2011–2013 due to the cumulative effects of fragmentation by dams and consecutive years of moderate to severe drought in the Arkansas River in Kansas (Perkin *et al.*, 2015b). These 2 y of drought encompassed the entire known range of Peppered Chub during summer 2011 and 2012 [see Fig. S4 in Perkin *et al.* (2015b) for intensity and geographic extent of the drought].

The Peppered Chub is a short-lived (approximately 2.5 y; Bonner, 2000), relatively small minnow (max total length = 77mm; Eisenhour, 1999) that inhabits shallow, flowing reaches over clean, sand-gravel substrate (Perkin, 2014). They belong to a highly threatened reproductive guild or ecotype that spawn semi-buoyant eggs into the water column that drift downstream as they develop over several days (pelagic spawners; Bottrell *et al.*, 1964; Perkin and Gido, 2011; Worthington *et al.*, 2014). Survival and reproductive success are thought to be reliant on river discharge (Wilde and Durham, 2008) and connectivity (Perkin and Gido, 2011) because eggs must remain in suspension to avoid settling to the river bottom and being covered in sediment. Hatching occurs after 24–48 h, and larvae continue to drift and develop for 2–3 d before becoming free-swimming (Platania and Altenbach, 1998; Perkin and Gido, 2011). The Peppered Chub is part of the *Macrhybopsis aestivalis* complex, which prior to the work of Eisenhour (2004), consisted of six subspecies: *M. a. aestivalis, M. a. australis, M. a. hyostoma, M. a. marconis, M. a. sterletus, and M. a. tetranemus.* Eisenhour (1999) elevated the Peppered Chub to the species level, distinguishable from other members of the *M. aestivalis* complex based on a suite of morphological characteristics; most notably by its two pairs of long barbels. The Peppered Chub is endemic to the Arkansas River mainstem and its major tributaries in Kansas, Oklahoma, Colorado, New Mexico, and Texas (Eisenhour, 2004). Peppered Chub are currently classified as endangered in Kansas, threatened in New Mexico, species of greatest conservation concern in Texas, and extirpated in Colorado and Oklahoma (Luttrell *et al.*, 1999; Miller and Robison, 2004).

The Peppered Chub was reported to be extirpated from 90% of its historical range and thought to remain in only two geographically isolated populations (Luttrell *et al.*, 1999). One population occurred in parts of the Ninnescah and Arkansas rivers in south-central Kansas and a second in the Canadian River between Ute Reservoir in New Mexico and Meredith Reservoir in Texas (Fig. 1). The Arkansas River in Kansas remains dry throughout the western half of the state and is fragmented by multiple dams along its flowing portions. The Ninnescah River has several low-head dams occurring on the south fork and a large reservoir (Cheney Reservoir) on the north fork. The reach of the Arkansas River that has historically maintained Peppered Chub consists of approximately 140 km downstream of Wichita, Kansas to the upper portions of Kaw Reservoir in Oklahoma. An additional 146 km of river persists in the Ninnescah River downstream of Kingman, Kansas to the confluence with the

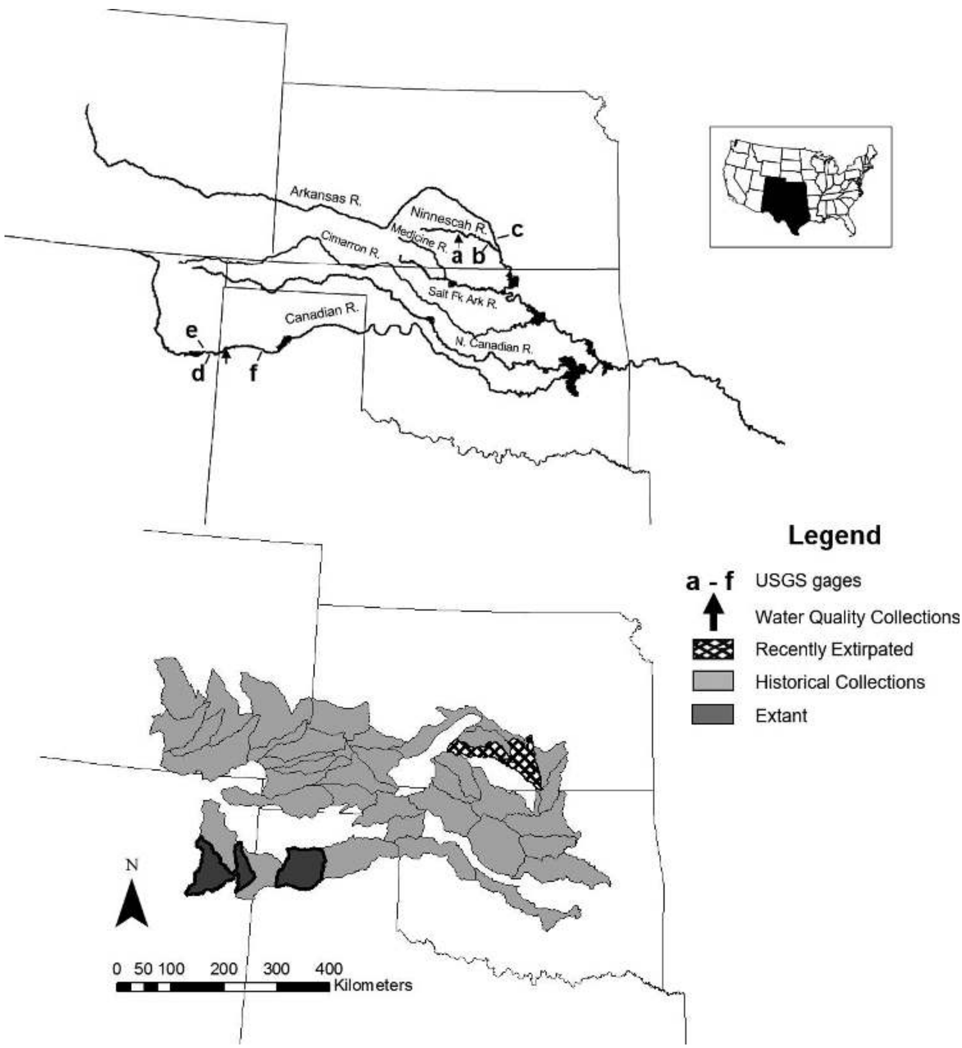

FIG. 1—Top) Major rivers and associated water storage reservoirs of the Upper Arkansas River Basin where the Peppered Chub is endemic. Also depicted are USGS gaging stations and EPA STORET water quality collection locations used in data analyses. Bottom) Occurrence records (NatureServe, 2016; modified by the authors) at a USGS 8-digit Hydrologic Unit Code scale depicting the historical range of the Peppered Chub, alongside the extant (Canadian River) and recently extirpated (Ninnescah/ Arkansas River) reaches

Arkansas River. The Canadian River population of Peppered Chub is confined to a 220 km reach of river by two large reservoirs (Perkin *et al.*, 2015a).

Peppered Chub are highly susceptible to the coupled effects of fragmentation and drought because they require large intact river reaches (*i.e.*, >100 km) to complete their life history (Perkin and Gido, 2011) and are relatively short lived (Bonner, 2000). Consequently,

TABLE 1—Recent museum records for Peppered Chub by state. Institution codes where specimens are housed are in parenthesis and represent: Fort Hays Sternberg Museum (FHSM), KU Biodiversity Institute (KU), Sam Noble Oklahoma Museum of Natural History (OMNH), Museum of Southwestern Biology (MSB), and Texas Natural History Collections (TNHC). Records were obtained from VertNet and FishNet2 repositories

Year	Kansas	New Mexico	Texas
1999	1 (FHSM)		1 (TNHC)
2000	1 (KU)		
2001	2 (KU)		
2002	1 (KU)		
2003	1 (KU)		
2007			2 (OMNH)
2009		1 (MSB)	

2 y of failed recruitment could have detrimental effects on their populations (Wilde and Durham, 2008). Thus, we compiled recent collecting activities to assess the status of Peppered Chub across its known range following severe drought occurring in 2011 and 2012. Specifically, we assessed if Peppered Chub populations were able to persist during and rebound following drought in Kansas and New Mexico. We also describe long term discharge and water quality from locations along river fragments in Kansas, New Mexico, and Texas where Peppered Chub were thought to still occur to identify trends that might influence their persistence.

METHODS

We compiled records of Peppered Chub throughout its range to capture records of occurrence before and after the drought of 2011 and 2012. These records included museum specimens since the review by Luttrell *et al.* (1999; Table 1), sampling by the Kansas Department of Wildlife, Parks, and Tourism (KDPWT) on the Ninnescah River (1994–2003), sampling by the City of Wichita (COW) on the Arkansas River (1991-2007), sampling by Kansas State University (Perkin *et al.*, 2015b; unpublished data by the authors) on the Arkansas and Ninnescah rivers (2011–2015), multiple sampling efforts in the Canadian River and associated tributaries in New Mexico (1991–2012; D. L. Propst, unpublished data), and recent sampling conducted by the New Mexico Department of Game and Fish and the U.S. Fish and Wildlife Service from 2013–2015 on the Canadian River downstream of Ute Reservoir.

Sampling effort was variable across studies (Table 2). In Kansas 32 localities sampled on the Ninnescah (between 37°39′42”N, 98°30′07”W and 37°23′29”N, 97°20′19”W) and Arkansas (between 37°40′16”N, 97°20′38”W and 37°18′54”N, 97°09′36”W) rivers encompassed areas where Peppered Chub were previously caught. Sampling gears consisted of either a combination of tote barge electrofishing and seining 300 m reaches (*i.e.*, KDWPT and COW) or only seining in all available habitats for approximately 1 h (*i.e.*, Perkin *et al.*, 2015*b* and this study). All sites visited during this study on the Ninnescah River were sites sampled by Perkin *et al.* (2015*b*) in 2011-2013. Sampling on the Arkansas River occurred at sites previously sampled by other projects (*i.e.*, KDWPT, COW, and Perkin *et al.*, 2015) and opportunistically sampled reaches that historically maintained Peppered Chub. Sampling records from the Canadian River system in New Mexico were located between Ute Dam (35°20′42”N, 103°26′32”W) to the New Mexico/Texas border (35°23′37”N,

TABLE 2—Sampling efforts from multiple collections in Kansas and New Mexico from 1990-2015. Records from the Arkansas and Ninnescah rivers in Kansas and the Canadian River in New Mexico were used to assess the post-drought status of Peppered Chub in the only two remaining populations

State	Rivers	Collectors	Gear	Years	Number of Peppered Chub	Number of Sampling Events	Mean Number of Fishes per Sampling Event	Total Number of Fishes Collected
Kansas								
	Arkansas	City of Wichita	tote barge electrofishing, seining	1991-2007	264	133	1909	253,879
	Ninnescah	Kansas Dept. of Wildlife, Parks and Tourism	tote barge electrofishing, seining	1994-2003	55	40	2185	87,401
	Arkansas, Ninnescah	Perkin et al. (2015), Kansas State University unpub. data	seining	2011-2013	47	211	938	197,972
	Arkansas, Ninnescah	Sampling by authors	seining	2015	0	64	1100	70,371
New Mexico								
	Canadian, Revuelto Ck.	D. L. Propst, unpub. data	seining	1990-2012	596	38	558	21,202
	Canadian, Revuelto Ck.	NMDGF and USFWS	seining	2013-2015	261	64	817	52,295

103°02′36”W). This 56 km stretch of river included Revuelto Creek an ephemeral tributary that often flows during storm events and was sampled as part of ongoing monitoring efforts for the threatened Arkansas River Shiner *Notropis girardi*. Discrete mesohabitats were seined in proportion to their occurrence within a site. Due to the variable effort among datasets we transformed data into catch per unit effort (CPUE). Catch per unit effort was calculated as the number of Peppered Chub collected divided by the number of sampling events in a year. We used CPUE to describe patterns in Peppered Chub collections before and after the most recent drought in Kansas and New Mexico.

We feel it is important to acknowledge that the variable sampling efforts combined with small population sizes may have influenced our detection ability (*i.e.*, imperfect detection). However, the habitat from which Peppered Chub are commonly collected (*i.e.*, runs <1 m in depth, over clean sand or gravel) is easily sampled with seines and can produce a large number of individuals if they are abundant in the system (*e.g.*, Cross, 1950; Wilde *et al.*, 2001). Sampling efforts in Kansas were at least as intense as, and collected more individual fishes per sampling event than, sampling in New Mexico where Peppered Chub were collected following the most recent drought. Moreover, previous sampling in Kansas produced Peppered Chub consistently and in greater abundance than more recent sampling despite comparable sampling efforts in reaches that historically maintained Peppered Chub.

To evaluate flow regimes in the Arkansas and Canadian rivers that might influence persistence of Peppered Chub, we used the software program Indicators of Hydrologic Alteration (IHA; Richter *et al.*, 1996) to calculate mean monthly discharge (m^{-3} s^{-1}) and the number of high flow pulses for the period between 1970 and 2015 for gages located on the South Fork Ninnescah (USGS gage #07145200), Ninnescah (0714550), and Arkansas (07144550) rivers in Kansas; and Revuelto Creek (07227100) in New Mexico and the Canadian River in New Mexico (07227000) and Texas (07227500). A high flow pulse is a daily discharge exceeding one standard deviation of the long term mean. We chose these two flow parameters because they reflect annual variation in climate (*i.e.*, drought) and their importance to the spawning success of Peppered Chub both by means of egg and larval transport and by providing cues to induce and synchronize spawning (Wilde and Durham, 2008). Additionally, we evaluated water quality in the Canadian River in Texas and the South Fork Ninnescah River in Kansas using data from the U. S. Environmental Protection Agency’s STORET Database (https://www.epa.gov/waterdata/storage-and-retrieval-and-water-quality-exchange) to identify other factors that might influence the persistence and recovery of Peppered Chub.

RESULTS AND DISCUSSION

The last collections of Peppered Chub in Kansas consisted of one individual from the Ninnescah River (Perkin *et al.*, 2015b) and two individuals from the Arkansas River (R. Waters, KDWPT, unpublished data), both of which were collected in 2012. In contrast Canadian River Peppered Chub CPUE declined during the drought in 2012, but they persisted and had rebounded by 2015 (Fig. 2). Peppered Chub were collected in every year prior to and even during the most recent drought, but CPUE declined to zero after the drought in Kansas. Long-term and drought-year (2011–2012) mean monthly discharges were nearly an order of magnitude higher in the Arkansas and Ninnescah rivers when compared to the Canadian River system (Fig. 3). The reach of Canadian River examined appears to be a more seasonal system than the Arkansas and Ninnescah rivers, showing higher mean discharge during summer (June-September) than the South Fork Ninnescah in Kansas.

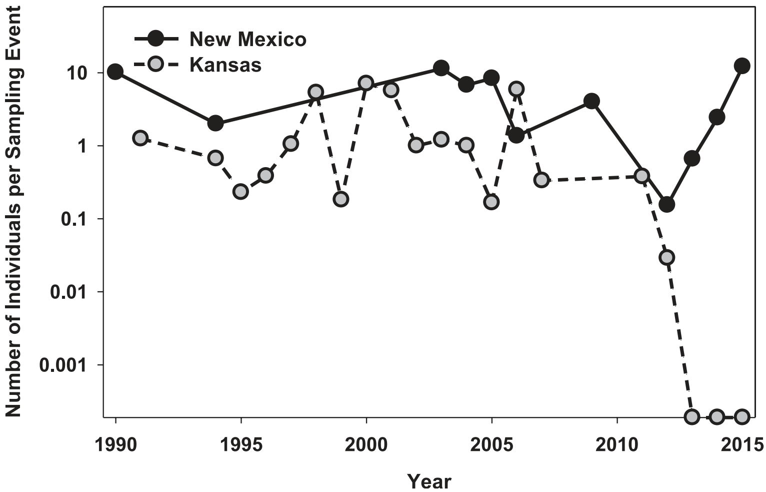

FIG. 2—Catch per unit effort on a Log scale of Peppered Chub in Kansas and New Mexico from 1990-2015. No Peppered Chub were collected from Kansas after 2012. Methods used varied by researchers conducting sampling[a]

[a]Sampling in 2005 in New Mexico was intensive depletion sampling of 100 m using three seine crews working simultaneously at each of five sites (SWCA, 2011). For comparison each seine crew and pass was considered a sampling event

Rivers in Kansas all experienced peak flows in June while all rivers in New Mexico and Texas peaked in August. During the most recent drought in 2011 and 2012, flows in the Canadian River, New Mexico were maintained somewhat due to seepage flow from Ute Reservoir dam. Seepage from the dam maintains baseflows of approximately 0.08 m^{-3} s^{-1} until the river's confluence with Revuelto Creek, an unmanaged perennial tributary, which has a median discharge of 0.12 m^{-3} s^{-1} (S. Davenport, unpublished data). High flow pulses from Revuelto Creek likely provided spawning cues for pelagic spawners in the Canadian River in New Mexico that were reduced or absent during drought years in Kansas (Fig. 4). Contributions from small tributaries both in flow pulses and sediments may be important for the reproductive success of Peppered Chub. The fact Peppered Chub persisted the drought in the lower flows of the Canadian River is suggestive that high flow pulses may be more important than base flows to the persistence of this species, but further research would be needed to confirm this hypothesis.

There may be other factors contributing to the decline of Peppered Chub including water quality, pollution, and possibly the interactions between these and other factors coinciding with fragmentation (Hoagstrom *et al.*, 2011). Water quality issues may have impacted Peppered Chub in the Arkansas River in the summer of 2012. During May of 2012, a fish kill occurred downstream of the City of Wichita when the Lincoln Street Dam was raised halting all flow downstream for 1–2 d. The fish kill was a result of a water treatment facility leaking untreated sewage into the Arkansas River. The combination of drought induced low flows (*i.e.*, below the 95% confidence levels of the long term mean annual discharge; Perkin *et al.*, 2015b) and the raising of the dam led to flows in the river consisting entirely of contaminated effluent. No Peppered Chub were identified among the 652 fishes collected but only three sites were visited in a 2.4 km stretch of river by KDWPT biologists (R. Waters,

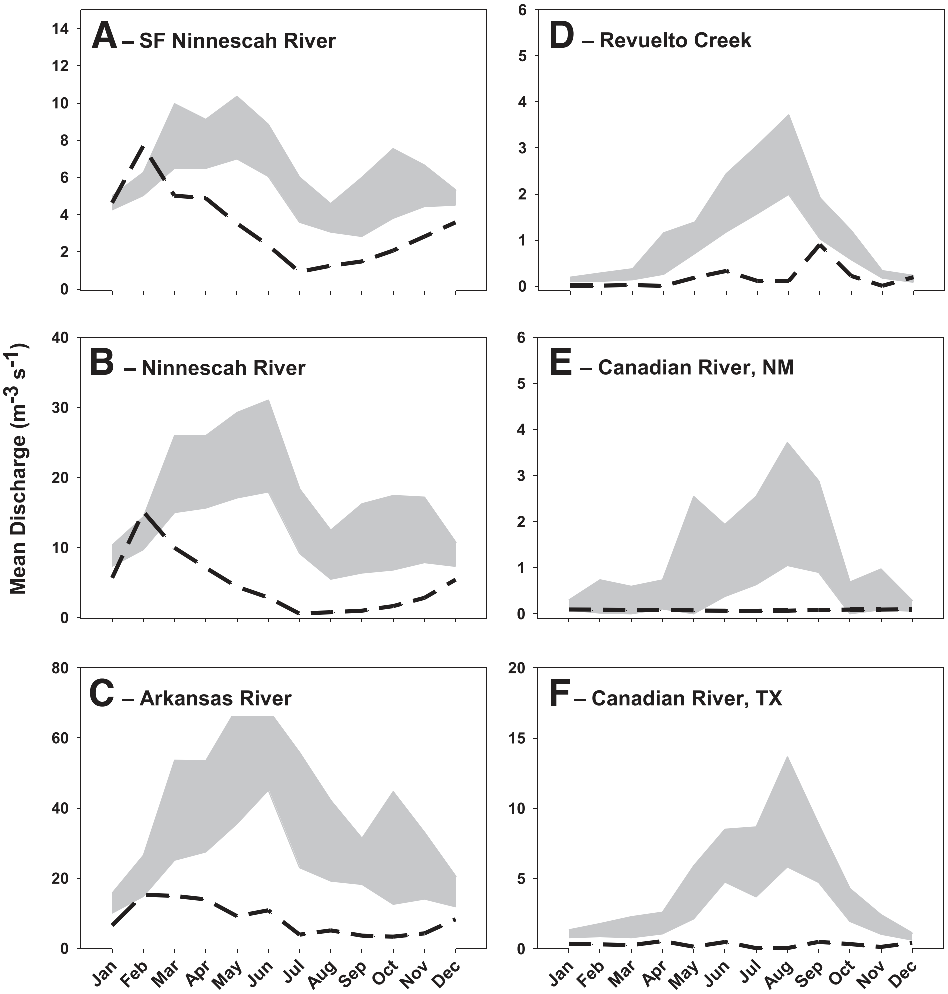

FIG. 3—95% confidence interval bands of mean monthly discharge (1970-2015, grey shading) for the reaches of river last known to maintain Peppered Chub in Kansas (left), and New Mexico and Texas (right). Mean monthly discharge for 2011-2012 (dashed line) is shown to illustrate the effects of the drought on discharge. Y-axes are scaled differently for each panel. Letters correspond with USGS gage locations labeled in Fig. 1

pers. comm.). Salinity is another factor that could have assisted in the persistence of Peppered Chub in the Canadian River despite lower flows. Salinity effects the buoyancy and developmental rate of the eggs of pelagic-spawning minnows (Mueller, 2013). Faster developmental rates could reduce the length of river that eggs and larvae require before becoming free-swimming (Mueller, 2013). Average annual total dissolved solids (TDS) in the Canadian River downstream of the New Mexico/Texas border (Fig. 1) ranged from 2523–6970 mg/L (4868 ± 1237; mean ± sd) in 1985-2011, and from 434-814 mg/L (572 ± 113) in 1999–2012 in the SF Ninnescah River at Murdock, Kansas. Therefore, although discharge

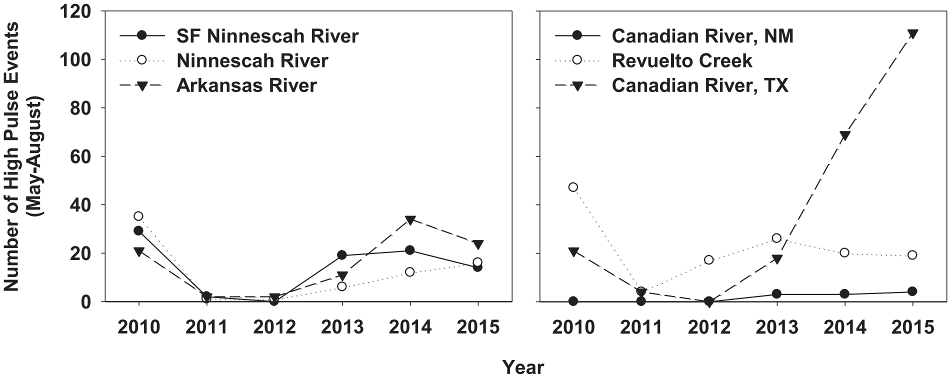

FIG. 4—Number of high flow pulses during spawning months (May – August) of Peppered Chub in Kansas (left) and New Mexico and Texas (right) before, during, and after the most recent drought years in 2011 and 2012. Rivers are listed in the legend from upstream to downstream. A high flow pulse event was classified as a mean daily flow that exceeded one standard deviation of the long term mean (1970-2015)

was generally higher in rivers in Kansas, higher TDS in the Canadian River could contribute to increased survival and reproductive success in the Canadian River population allowing them to be more resilient to the ratcheting effects of drought in fragmented systems.

If the Kansas population of Peppered Chub is extirpated, the only remaining population occurs within a highly regulated reach of the Canadian River that has experienced an 88% decline in mean annual discharge since impoundment by Ute Reservoir in New Mexico (Costigan *et al.*, 2012). Given this severe range contraction, Peppered Chub might face extinction unless immediate actions are taken. Much of the historical habitat of the Peppered Chub has been lost completely due to river desiccation following groundwater extraction from the Ogallala Aquifer formations in the upper portions of the Cimarron and Arkansas rivers (Cross *et al.*, 1985). However, declines of the Peppered Chub also coincide with the construction of reservoirs (Luttrell *et al.*, 1999) and the ratcheting mechanism created by the coupled effects of fragmentation and drought (Perkin *et al.*, 2015b). Fragmentation and habitat loss has isolated remaining populations such that natural recolonization is not possible and the only way for Peppered Chub to re-establish in historical reaches, from which the species has been lost, is through repatriation from the Canadian River. This makes the reach of Canadian River shared by New Mexico and Texas of high conservation value. Conservation efforts that help preserve and recover this species include maintenance of river discharge and flow variability (*i.e.*, high flow pulses) and captive spawning programs may need to be started with individuals from the Canadian River to ensure repatriation efforts are possible (Osbourne *et al.*, 2014).

It is notable that Peppered Chub have persisted in the Canadian River system, where discharge is much less than river systems elsewhere in the Arkansas River basin. Wilde and Durham (2008) developed a life history model for this population of Peppered Chub and discharge was the best predictor for age-0 survival. They concluded post-impoundment discharge of the Canadian River, New Mexico and Texas has not been maintained at a level necessary to maintain a stable population (*i.e.*, average annual discharge = 11.9 m^{-3} s^{-1}). Over the course of their 6 y sampling period (1996 to 2001), an 80% decline in CPUE of Peppered Chub was documented, and based on estimated age-1 survival, an 89% population

TABLE 3—River reaches that have maintained average annual flows (1980-2015) predicted to allow for stable populations of Peppered Chub (Wilde and Durham, 2008), and which have fragment length characteristics necessary for the completion of Peppered Chub life history (Perkin and Gido, 2011). Fragment length was determined from data reported by Perkin *et al.* (2015*b*)

River	Fragment Length (river km)	Discharge ± S.D. (m^{-3} s^{-1})	USGS gage
Cimarron River between Old Settlers Diversion Dam and Keystone Reservoir, Oklahoma	528	22.9 ± 11.2	07159100
Arkansas and Salt Fork Arkansas Rivers downstream of Great Salt Plains and Kaw Reservoirs, Oklahoma	292	31.8 ± 13.9	07151000
Arkansas and Ninnescah Rivers between Wichita/ Kingman, Kansas and Kaw Reservoir, Oklahoma	251	30.8 ± 14.4	07144550
Arkansas River between Great Bend and Wichita, Kansas	178	12.3 ± 5.8	07143330

decline was predicted following a single failed reproductive event. Average annual discharge in the Arkansas and Ninnescah rivers during 2011 and 2012 were comparable to the 11.9 m^{-3} s^{-1} recommended by Wilde and Durham (2008) but were not enough to maintain a stable population in Kansas. Despite the disappearance of the Peppered Chub across its historical range, there still remain several reaches of river where repatriation could prove successful (Table 3). These reaches have lengths ranging from 178 to 528 km (Perkin *et al.*, 2015a) and have maintained an average annual discharge greater than 12 m^{-3} s^{-1} determined from USGS gage data (1980–2015).

Regardless of the persistence of this population in Kansas, it is clear the Peppered Chub has experienced declines throughout its entire range and what was once considered a refuge for the species (Hoagstrom *et al.*, 2011) might now be considered a place of recent extirpation. Previous studies (*e.g.*, Cross and Moss, 1987; Cross and Collins, 1995; Eisenhour, 1999; Luttrell *et al.*, 1999; Gido *et al.*, 2010; Perkin *et al.*, 2015*b*) have documented the decline of this and similar Great Plains riverine specialists over the past three decades. Repatriation or supplemental stocking as is done elsewhere for small-bodied cyprinids (*e.g.*, endangered Rio Grande Silvery Minnow *Hybognathus amarus* in New Mexico; Osborne *et al.*, 2013) is now a necessary first step in recovery, but this alone might not be sustainable or sufficient without taking the proper actions to remedy habitat deficiencies. Specifically, removing (or modifying to allow fish passage) the remaining barriers impeding upstream recolonization of rivers throughout the species' historical range and maintaining adequate seasonal river flows to support juvenile survival (Wilde and Durham, 2008; Perkin *et al.*, 2015*a*) is likely necessary for recruitment. Construction of a fish passage structure on the Arkansas River in Wichita, Kansas was recently completed in 2010. This fish passage was built specifically for the passage of small-bodied fishes. Although it only reconnects 9 km of river before another low-head dam blocks upstream movement of fishes, it has already allowed for the recolonization of Emerald Shiner *Notropis atherinoides* into a reach of river from which the species was previously extirpated (Pennock, 2016) suggesting that fish passage structures such as this can restore upstream connectivity for small-bodied Great Plains fishes.

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