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RESEARCH ARTICLE

Ecohydrological index, native fish, and climate trends and relationships in the Kansas River basin

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Abstract

This study quantified climatological and hydrological trends and relationships to presence and distribution of 2 native aquatic species in the Kansas River basin over the past half century. Trend analyses were applied to indicators of hydrologic alteration (IHAs) at 34 streamgages over a 50-year period (1962–2012). Results showed a significant negative trend in annual streamflow for 10 of 12 western streamgages (up to −7.65 mm/50 years) and smaller negative trends for most other streamgages. Significant negative trends in western basin streamflow were more widespread in summer (12 stations) than in winter or spring (6 stations). The negative-trend magnitude and significance decreased from west to east for maximum-flow IHAs. Minimum-flow IHAs, however, significantly decreased at High Plains streamgages but significantly increased at Central Great Plains streamgages. Number of zero-flow days showed positive trends in the High Plains. Most streamgages showed negative trends in low- and high-flow pulse frequency and high-flow pulse duration, and positive trends in low-flow pulse duration. These results were consistent with increasing occurrence of drought. Shift in occurrence from present (1860–1950) to absent (2000–2012) was significantly related ($p < .10$) to negative trends of 1-day maximum flows (both species) and indices associated with reduced spawning-season flows for Plains Minnow and shifting annual-flow timing and increased flow intermittency for Common Shiner. Both species were absent for all western basin sites and had different responses to hydrological index trends at eastern basin sites. These results demonstrate ecohydrological index changes impact distributions of native fish and suggest target factors for assessment or restoration activities.

KEYWORDS

Common Shiner, ecohydrology, hydrologic change impacts, hydrologic indices, Plains Minnow, trend analysis

1 | INTRODUCTION

Streamflow trend analysis provides important insights and understanding of historical responses to changes in climate, land cover, and landscape management. Numerous analyses of streamflow trends have been presented at state (Aguilar, 2009; Kibria, Ahiablame, Hay, & Djira, 2016), regional (Clow, 2010; Ryberg, Akyuz, Wiche, & Lin, 2015; Stewart, Cayan, & Dettinger, 2005), and national (Dudley, Hodgkins, McHale, Kolian, & Renard, 2017; Lins & Slack, 2005) scales. This study presents an extensive regional trend analysis of streamflow characteristics for the Kansas River basin (KRB) with the purpose of providing insights and understanding to observed shifts in distribution of two native fish species.

Natural flows in streams and rivers have been impacted by both climate (Gleick & Chalecki, 1999; Groisman, Knight, & Karl, 2001; Hodgkins, Dudley, & Huntington, 2003; Hodgkins, Dudley, & Huntington, 2005; Novotny & Stefan, 2007) and human activities (Khedkar, Lutzky, Rathod, Kalyankar, & David, 2014; Poff, Bledsoe, & Cuhaciyan, 2006; Poff & Zimmerman, 2010; Taylor, Seilheimer, & Fisher, 2014). Climate and landscape change has led to temporal and spatial variations in hydrological regimes across North America (Bower, Hannah, & McGregor, 2004; Knight, Gain, & Wolfe, 2012; Lynch et al., 2016; Poff, 2002) as well as regionally, including the KRB (Brunsell, Jones, Jackson, & Feddema, 2010; Lin & Brunsell, 2013).

These alterations in natural flow regimes have had a profound influence on aquatic organisms and habitat (Gasith & Resh, 1999;

Jowett & Duncan, 1990; Lytle & Poff, 2004; Poff & Allan, 1995). Climate-induced hydrological changes to North American inland fish species include shifts in spatial distribution, abundance, and phenology (e.g., migrations and spawning) and exhibit altered population dynamics (changes to abundance, growth, and recruitment) and genetic changes (or hybridization; Lynch et al., 2016). Flow regulation by various forms of river impoundment has been linked to reduced abundance of fish larvae (Scheidegger & Bain, 1995), suppressed growth rates (Weisberg & Burton, 1993), altered community structure (Bain, Finn, & Booke, 1988; Gido, Propst, Olden, & Bestgen, 2013), reduced species diversity (Alexandre, Ferreira, & Almeida, 2013; Gehrke, Brown, Schiller, Moffatt, & Bruce, 1995; Small, Bonner, & Baccus, 2009), and introduction of invasive species (Alexandre et al., 2013; Brown & Bauer, 2009; Perkin & Bonner, 2011).

Studies of hydrological variability using hydrological indices are ubiquitous. Water resource indicators (WRIs), such as monthly, seasonal, and annual flows and centre of timing (CT) of annual flows, have been used in many studies as indicators of hydrological impacts of climate change (Dibike & Coulibaly, 2005; Merritt et al., 2006; Shrestha, Peters, & Schnorbus, 2013; Toth, Pietroniro, Conly, & Kouwen, 2006). In addition, the indicators of hydrologic alteration (IHAs; Richter, Baumgartner, Powell, & Braun, 1996; The Nature Conservancy, 2009), an expanded version of the WRIs, are considered to reflect the most influential hydrological factors in ecological studies (Poff et al., 1997; Risbey & Entekhabi, 1996; The Nature Conservancy, 2009). These indicators provide detailed representations of the hydrological regime and characterize intra-annual variability in water conditions (The Nature Conservancy, 2009).

Numerous studies globally have used IHAs to characterize the flow-related changes (preregulation and postregulation scenarios) in regulated rivers (Shieh, Guh, & Wang, 2007; Small et al., 2009; Tharme, 2003; Wang, Rhoades, & Wang, 2016). In a few cases, data were available and sufficient to relate those changes to measured responses in habitats (Rypel, Haag, & Findlay, 2009; Mortenson & Weisberg, 2010; Martínez-Capel, Belmar, Bruno, & Velasco, 2013) and aquatic species (Alexandre et al., 2013; Arthington, Rolls, Sternberg, Mackay, & James, 2014; Gido et al., 2013; Perkin & Bonner, 2011; Quinn & Kwak, 2003; Rypel et al., 2009). These relationships have varied widely by region, reflecting local ecohydrological factors (Gido et al., 2013). More research is critical to quantify regional relationships between IHAs and aquatic species responses.

The objectives of this study were to quantify magnitude and significance of temporal trends in climatic and ecohydrological variables (WRIs and IHAs) using long-term climate and nonimpounded watershed streamflow data in the KRB; determine the degree of spatial and temporal relationships between climatic variables, ecohydrological indicators, and ecoregional structure of the KRB; and evaluate the extent to which trends in ecohydrological indicators can differentiate between current presence or absence of native aquatic faunal species at sites where they were present historically. A central hypothesis of this study was that alterations in streamflow and associated aquatic habitat suitability have occurred historically within the KRB and can be used to explain the observed shift in presence of native aquatic fauna.

2 | METHODS AND MATERIALS

2.1 | Study area

The KRB is located within northern Kansas, southern Nebraska, and eastern Colorado (Figure 1). The Kansas River is vitally important to the social, economic, and ecological character of these regions. It is formed by the union of the Republican River and the Smoky Hill River, and its outflow forms a confluence with the Missouri River. The KRB covers an area of 155,000 km^2 (60,000 mi^2) and includes some of the largest tracts of native prairie left in the United States. It spans six U.S. Environmental Protection Agency (EPA) level-III ecoregions: High Plains, Central Great Plains, Flint Hills, Western Corn Belt Plains, Central Irregular Plains, and Nebraska Sand Hills (Figure 1). These ecoregions contain productive grasslands and croplands. Flint Hills contains some of the largest native prairie left in the United States. These conditions make the KRB an important region for agriculture and conservation.

The KRB has a prevailing east-to-west precipitation gradient and spatial variability in biophysical factors (e.g., soil quality, water availability, and land use), which provides a range of conditions for hydroecological study (Sinnathamby, 2014). Agriculture and prairie are dominant land covers of the KRB. Croplands are distributed primarily in the central to west, grasslands range from tallgrass prairie in the east to shortgrass prairie in the west, and woodlands progress from hardwood forest in the east to riparian vegetation in the central KRB. Future shifts in land cover are expected with increasing biofuel demands in the Midwest Corn Belt region. KRB has an average rainfall of about 1,000 mm/year in the east and 400 mm/year in the west (Lin & Brunsell, 2013). The basin has a wide gradient of soil permeability, with lowest levels in the eastern one third and moderate to high levels in the western two thirds. The highest permeability is observed in the northwestern KRB. The flood potential is higher in areas with low soil permeability area than in areas with higher soil permeability. The higher soil permeability areas tend to allow more infiltration and lower run-off, which may allow greater baseflow contribution to the stream (Perry, Wolock, & Artman, 2004).

The High Plains Aquifer, one of the largest aquifers in the United States, is beneath nearly half of the KRB. The groundwater condition in High Plains Aquifer is generally defined as unconfined. Its saturated thickness ranges from 15.2 m to about 350.5 m (McGuire, Lund, & Densmore, 2012). The High Plains Aquifer underlays much of the nation's primary agriculture regions. In parts of Texas, Oklahoma, and southwestern Kansas, the High Plains Aquifer has declined more than 30.5 m in water level due to groundwater withdrawals for irrigation (Luckey, Gutentag, & Weeks, 1981; McGuire, 2001).

2.2 | Dataset and site selection

A set of 34 U.S. Geological Survey (USGS, 2014) streamgages (Figure 1 and Table 1) located across the KRB was used in this study. These streamgages were selected on the basis of Brimley et al. (1999) and Harvey, Pilon, and Yuzyk (1999) station selection criteria: (a) sites with natural flow conditions, (b) absence of diversions, dams, or other

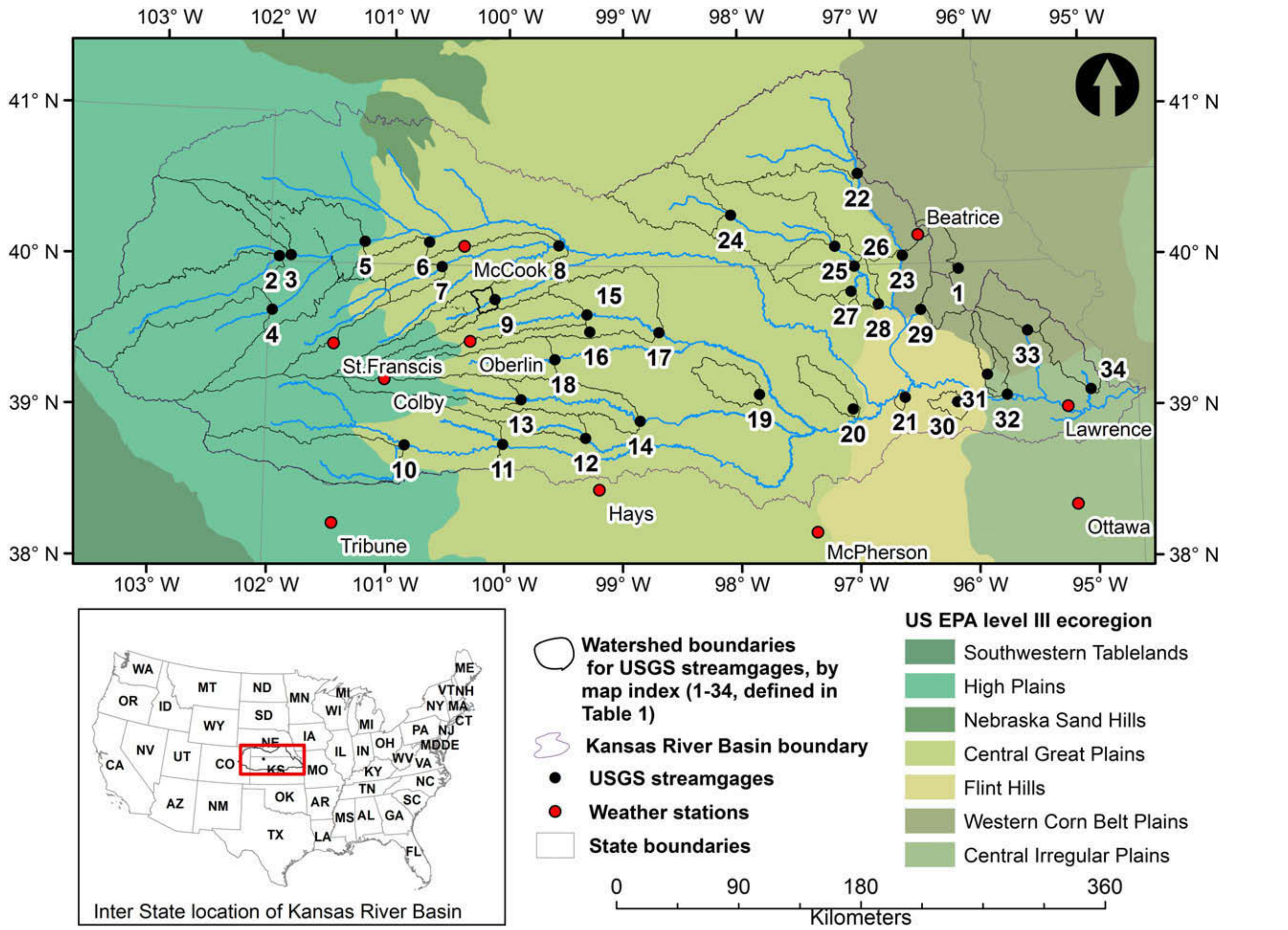

FIGURE 1 Locations of U.S. Geological Survey (USGS) streamgages and their watershed boundaries, weather stations, and U.S. Environmental Protection Agency (EPA) level III ecoregions within and around the Kansas River basin study area. Map index numbers are defined in Table 1

significant regulations, (c) minimum 20 years of data, (d) expected longevity of the station in the future, and (e) accurate data.

Daily mean discharge data for water years (WYs) 1962–2012 (where WY extends for 12 months ending on September 30 of the stated year) were extracted from the USGS National Streamflow Information Program website (https://waterdata.usgs.gov/ks/nwis/current/?type=flow, accessed on 4/12/2014). All streamgages have a minimum of 30 years of data with watershed size from 11.5 to 21,006 km^2 with a median of 2,113 km^2. A large majority of streamgages (82%) had more than 50 years of data over the study period. Three streamgages (map index numbers 21, 26, and 33) had data only for WYs 1980–2012. In this study, a minimum 30-year period was assumed to be adequate to ensure validity of the trend results (Kahya & Kalayci, 2004; Kite, 1991). To ensure a high level of accuracy, only the "approved for publication data" (USGS, 2014) for active hydrometric stations were used in this study. USGS quality assurance and quality control procedures for measuring stream stage and discharge can be found in Sauer and Turnipseed (2010) and Turnipseed and Sauer (2010).

The watershed draining to each USGS streamgage was assumed to represent conditions of the predominate ecoregion within the watershed boundaries. In all cases, the predominant ecoregion represented at least 50% of the watershed area (Figure 1).

2.3 | Calculation of ecologically relevant hydrological variables

For the calculation of ecologically relevant hydrological variables, daily average discharge data (cfs) obtained from the USGS National Streamflow Information Program website database were converted to daily average streamflow per unit watershed area (mm/day) to standardize the effects of drainage area on streamflow generation (Monk, Peters, Curry, & Baird, 2011), and all remaining analyses used these normalized daily streamflow depth data. Six WRIs and 33 IHAs were calculated using up to 50 WYs of data (1962–2012), which was more than the 35 years of data recommended (The Nature Conservancy, 2009).

Seasonal mean values were calculated as the mean daily streamflow depth from March through May (spring), June through August (summer), September through November (autumn), and December through February (winter). The CT of annual flow (day of occurrence of 50% annual flow from October 1 through September 30) was calculated from

$$CT = \sum(t_i\, q_i)/\sum q_i, \tag{1}$$

where t_i is time (days) from October 1 (beginning of WY) and q_i is the corresponding streamflow per unit area (mm/day) for day i. Because

TABLE 1 U.S. Geological Survey (USGS) streamgage attributes, map index numbers (used in tables and figures), periods of record, and assigned ecoregions used in this study

Map index	USGS station code	USGS streamgage name	Drainage area (km^2)	Period of record (years)	Predominant ecoregion[a]	Area in selected ecoregion (%)
1	06814000	Turkey Creek near Seneca, KS	713.83	50	WCB	100
2	06821500	Arikaree River at Haigler, NE	5,622.58	50	High Plains	100
3	06823500	Buffalo Creek near Haigler, NE	488.21	50	High Plains	100
4	06827000	South Fork Republican River near CO-KS State Line, KS	5,313.84	50	High Plains	100
5	06828500	Republican River at Stratton, NE	21,006.47	50	High Plains	99
6	06836500	Driftwood Creek near McCook, NE	935.01	50	CGP	83
7	06846500	Beaver Creek at Cedar Bluffs, KS	4,357.76	50	High Plains	67
8	06847500	Sappa Creek near Stamford, NE	9,855.95	50	CGP	52
9	06847900	Prairie Dog Creek above Keith Sebelius Lake, KS	1,536.19	50	CGP	62
10	06860000	Smoky Hill River at Elkader, KS	9,033.35	50	High Plains	90
11	06861000	Smoky Hill River near Arnold, KS	12,897.80	50	High Plains	76
12	06863500	Big Creek near Hays, KS	1,417.27	50	CGP	85
13	06866900	Saline River near Wakeeney, KS	1,801.59	50	CGP	52
14	06867000	Saline River near Russell, KS	3,856.96	50	CGP	78
15	06871000	North Fork Solomon River at Glade, KS	2,424.41	50	CGP	82
16	06871500	Bow Creek near Stockton, KS	903.71	50	CGP	70
17	06872500	North Fork Solomon River at Portis, KS	6,217.07	50	CGP	92
18	06873000	South Fork Solomon River above Webster Reservoir, KS	2,698.83	50	CGP	71
19	06876700	Salt Creek near Ada, KS	1,056.44	50	CGP	100
20	06878000	Chapman Creek near Chapman, KS	776.42	50	CGP	100
21	06879650	Kings Creek near Manhattan, KS	11.51	32	Flint Hills	100
22	06881000	Big Blue River near Crete, NE	7,024.25	50	CGP	95
23	06882000	Big Blue River at Barneston, NE	11,512.53	50	CGP	86
24	06883000	Little Blue River near Deweese, NE	2,573.64	50	CGP	100
25	06884000	Little Blue River near Fairbury, NE	6,133.18	50	CGP	100
26	06884025	Little Blue River near at Hollenberg, KS	7,171.95	32	CGP	100
27	06884200	Mill Creek at Washington, KS	908.41	50	CGP	100
28	06884400	Little Blue River near Barnes, KS	8,655.96	50	CGP	100
29	06885500	Black Vermillion River near Frankfort, KS	1,062.87	50	WCB	100
30	06888500	Mill Creek near Paxico, KS	842.35	50	Flint Hills	100
31	06889200	Soldier Creek near Delia, KS	385.66	50	Flint Hills	65
32	06889500	Soldier Creek near Topeka, KS	748.58	50	WCB	52
33	06890100	Delaware River near Muscotah, KS	1,131.97	32	WCB	100
34	06892000	Stranger Creek near Tonganoxie, KS	1,092.72	50	WCB	56

[a]WCB = Western Corn Belt; CGP = Central Great Plains.

of the skewed nature of hydrological datasets, non-parametric statistics were used for most of the other indices. This resulted in presentation of median values for all IHA parameters, except 1- to 90-day minimums and maximums. The 1- to 90-day minimums and maximums were calculated from moving averages of every possible period. If multiple periods had the same value, the earliest period was reported. The 25th and 75th percentile flows were used as the thresholds for low- and high-flow pulse calculations. Flow reversals were calculated by dividing the hydrological record into "rising" and "falling" periods, which corresponded to periods in which daily changes (from the previous day) in flows were either positive (rising) or negative (falling). Flood and drought conditions were characterized by the magnitude and timing of events (annual maximum/minimum 1-, 3-, 7-, 30-, and 90-day mean flows) along with intra-annual and inter-annual variability in flow conditions (e.g., rise/fall rate and number of reversals in the hydrograph). Number of zero-flow days and baseflow index (7-day-minimum flow mean) indicators provided additional description of low-flow conditions. Detailed descriptions of the IHAs and their ecological significance can be found in the foundational IHA articles (Poff et al., 1997; Richter et al., 1996; The Nature Conservancy, 2009) and subsequent user studies (Monk et al., 2011; Sinnathamby, 2014).

2.4 | Trend analysis techniques

Trends in IHAs and WRIs from each streamgage were evaluated using Mann–Kendall trend analysis (Kendall, 1975; Kendall & Gibbons, 1990; Mann, 1945). The Mann–Kendall test is a non-parametric correlation statistical test and is appropriate for detecting linear trends of hydrological time-series data. The Mann–Kendall test is not affected by extreme values or skewness in the data, making it effective for analysing trends in streamflow (Rasmussen & Perry, 2001). The null hypothesis was that there was no trend in the series, and significance was tested at *p* values of .05 and .10 (where *p* is the probability of erroneously rejecting the null hypothesis, or saying there is a trend when there is not).

Sen's (1968) estimator of trend slope was included in the analysis to estimate the true slope (change per unit time) when there was a linear trend. Sen's slope estimator has been widely used in hydro-meteorological time series (Martinez, Maleski, & Miller, 2012; Tabari, Somee, & Zadeh, 2011). The MATLAB code written by Burkey (2006) was used to calculate Mann–Kendall tau and Sen's slope.

2.5 | Precipitation and temperature trend analysis

The Mann–Kendall test was applied to annual average data from 16 precipitation stations and 17 temperature stations. The data were gathered from Kansas State University weather data library (http://www.ksre.ksu.edu/wdl/, accessed on 5/22/2014), which includes data from the National Climatic Data Centre's database. All stations had 50 years of data (1962–2012 WYs) except the Beatrice temperature station in Western Corn Belt (Figure 2), which had 48 years (1962–2011 WYs). In addition, Pearson correlation coefficient (R) was used to analyse the trends between flow and climate data for eight sites with overlapping weather and streamflow data.

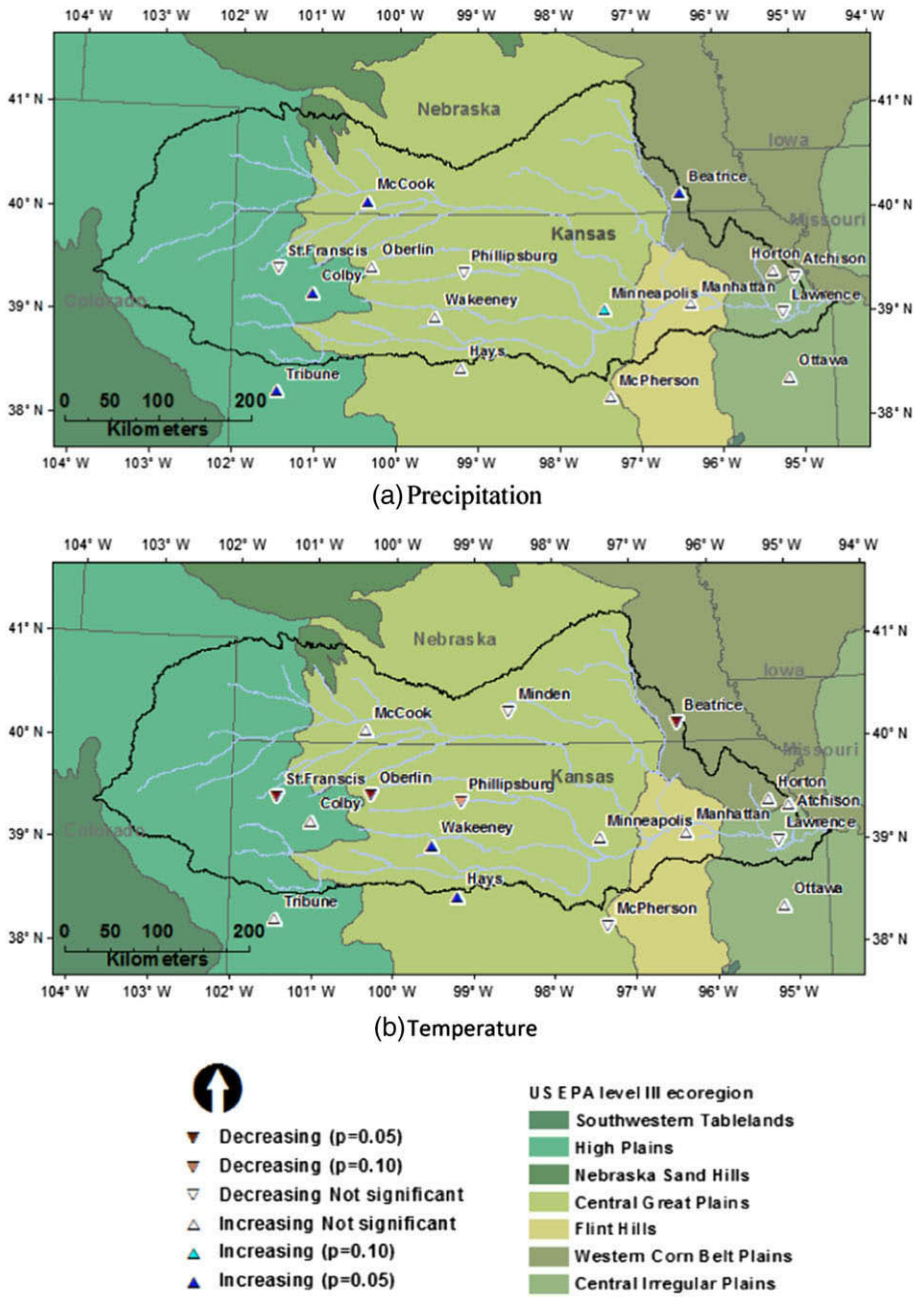

FIGURE 2 Trends (Mann–Kendall) in average annual (a) precipitation and (b) temperature at selected weather stations of Kansas River basin (water years 1962–2012)

2.6 | Ecological data and analysis

Fish occurrence data (presence/absence) at sites throughout Kansas were gathered from the Kansas Aquatic GAP Project database of the USGS National Gap Analysis Program (GAP; http://gapanalysis.usgs.gov/), which includes collections from the Kansas Department of Wildlife, Parks and Tourism, museum records, university research collections, and various other sources. The database includes more than 7,000 sites (collected between 1860 and 2012) represented by 133 fish species. The fish occurrence data are recommended to examine long-term functional responses of fish assemblages to hydrology rather than abundance (Mims & Olden, 2012; Gido, 2014, personal communication). For the analysis, the fish-streamgage pairs were identified in close geographic proximity by intersecting survey sites and streamgage watersheds using ArcGIS. Fish-streamgage pairs were selected such that fish survey sites were within 20 river kilometres (upstream or downstream) of the streamgage and were not separated by an impoundment (Mims & Olden, 2012). Two fish species native to Kansas and identified as threatened or in need of conservation (Distler et al., 2014) were selected for study: Plains Minnow (*Hybognathus placitus*) and Common Shiner (*Luxilus cornutus*).

The Plains Minnow occurs in shallow perennial streams with shallow, braided flow over broad beds of shifting sand. An adult Plains Minnow is about 13 cm in length. The Plains Minnow was abundant and widely distributed throughout the KRB and started to decline by 1970 (Taylor & Eberle, 2014). Changes in the streamflow volume, the pattern, and the fragmentation by dams were identified as major sources of decline (Gido, Dodds, & Eberle, 2010; Perkin & Gido, 2011). The Plains Minnow has been listed as a threatened species in Kansas.

Common Shiner occupies streams with coarse substrates. Adults are commonly 8–13 cm in length, and total length can range up to 18 cm. The Common Shiner was extirpated from northwestern Kansas streams due to turbidity and dewatering and has been listed as a species in need of conservation in Kansas and as a threatened species in Colorado (Cathcart, 2014).

Streamflow data were not available for the entire period of fish sampling (1860–2012), but for most streamgages, data were available since 1962 and span the period of most dynamic landscape change. Most reservoirs of the KRB were constructed and irrigation agriculture was initiated at a low level during 1947 to 1962 (Gido et al., 2010). Prior to 1947, streams were presumed to be natural and unimpounded. Rapid impoundment development and increase in irrigated land acreage (primarily in western Kansas) occurred during 1963–1977 (Cross & Moss, 1987; Eberle, 2007).

To analyse the relationship between ecohydrological variables and riverine fish species, the fish data were divided into two time periods: historical (1860–1950) and present (2000–2012). The historical period was selected prior to most impoundment and irrigation development and similar to Distler et al. (2014), and the present period was selected to correspond with a period of a comprehensive survey of many streams in Kansas and to allow sufficient lag time for effects of reservoir construction and groundwater pumping to occur (Gido et al., 2010). If a specific fish species was present for >3 years during the historical period, its presence or absence was determined for the present period for each selected gage. In this way, two treatment groups were created: historically present + currently present ("Present") and historically present + currently absent ("Absent").

A two-sample t test (assuming unequal variance) was used to test if trends in each ecohydrological index were different between the two treatment groups (Present and Absent). A significant difference in trends was used as an indication that species occurrence was sensitive to change in that ecohydrological index.

3 | RESULTS AND DISCUSSION

3.1 | Climate trends

Mean annual precipitation (1962–2012) showed a positive trend at 12 of 16 stations in the KRB up to 2.70 mm/50 years, with four of these trends being significant at $p < .05$ and 1 at $p < .10$ (Figures 2a and 3a and Table 2). The greatest positive trend in precipitation was observed at Beatrice station (Western Corn Belt). Similar positive trends in precipitation have been observed in other studies of Kansas climate (Garbrecht, Van Liew, & Brown, 2004; Hu, Woodruff, & Mudrick, 1998; Rahmani, Hutchinson, Harrington, Hutchinson, & Anandhi, 2014). Brunsell et al. (2010) found altered precipitation for the 21st century in Kansas, but with a slight increase in winter and decrease in summer and fall based on decadally averaged monthly outputs of 21 A1B scenario global climate models under the Special Report on Emissions Scenarios used in the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 4.

Mean annual temperature showed a mix of positive trends (10 of 17 stations, two significant at $p < .05$) up to 0.02 °C/year and negative trends (seven of 17 stations, three significant at $p < .05$ and 1 at $p < .10$) up to −0.02 °C/year (Figures 2b and 3b). The greatest positive trend in temperature was observed at Wakeeney station (Central Great Plains) and greatest negative trend at Beatrice (Western Corn Belt). Brunsell et al. (2010) reported a slightly greater magnitude of warming for Kansas in the 21st century, with the largest trends of 0.04 °C/year in summer and fall based on the mean of 21 A1B scenario monthly global climate model outputs from IPCC-4. Depending on seasonal timing, the effect of the positive precipitation trend on the local net water budget could be offset by the trend of increasing temperature due to its influence on increasing evapotranspiration. Conversely, the decreasing temperature trend could have a reinforcing effect and result in more of the precipitation being available for run-off or groundwater recharge.

3.2 | Streamflow per unit area trends

The spatial distribution and significance of trends (Mann–Kendall) in annual mean streamflow per unit area for the 50-year study period are presented in Figures 4 and 5. Many more streamgages show negative Sen's trend slopes (29 of 34 stations) than positive trend slopes (five of 34 stations) within the KRB (Figure 5). Streamflow trend magnitude, both annually and seasonally (Figure 5), tended to decrease from west to east in the KRB. Significant negative trends ($p < .05$) in annual streamflow were observed at six of seven streamgages in the High Plains as well as four additional streamgages in the western

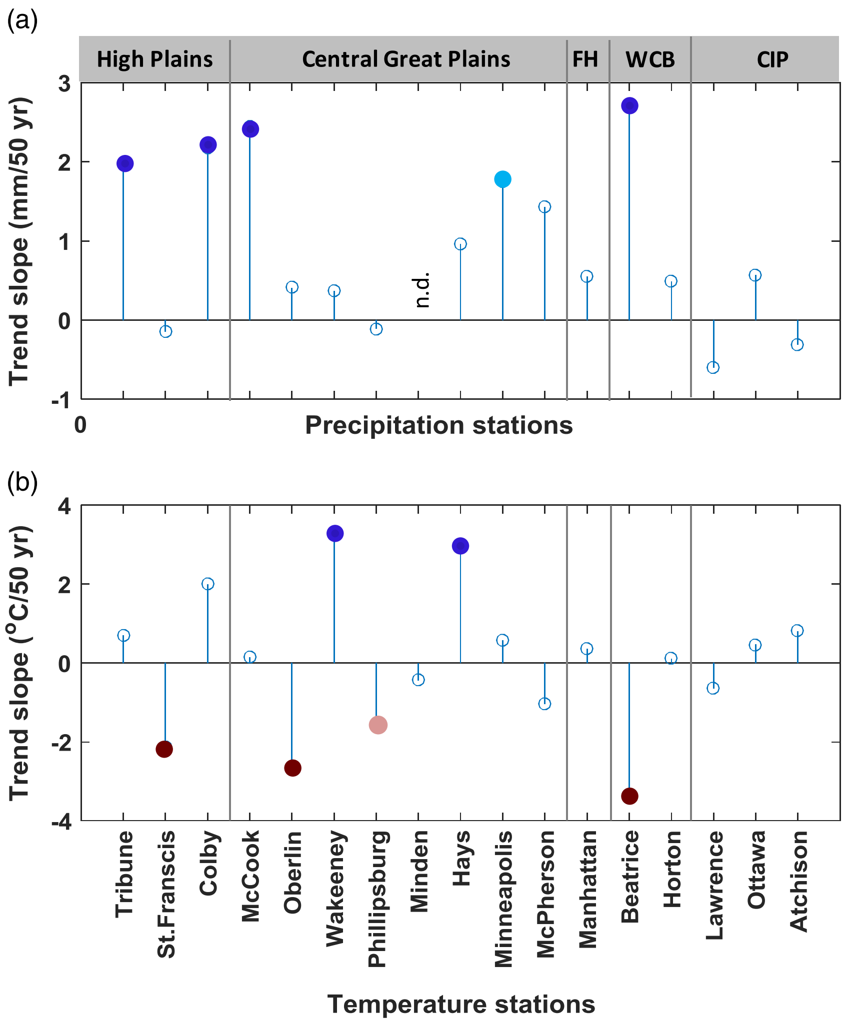

FIGURE 3 Trends (Sen's slope magnitude and significance) in (a) precipitation (b) temperature (water years 1962–2012) at stations in the Kansas River basin grouped by ecoregion: High Plains, Central Great Plains, Flint Hills (FH), Western Corn Belt (WCB), and Central Irregular Plains (CIP). Trend significance indicated by circles with dark fill (p = .05), light fill (p = .10), or no fill n.s. = not significant; n.d. = no data

Central Great Plains (Figures 4 and 5). The majority of streamgages in Central Great Plains, Flint Hills, and Western Corn Belt showed nonsignificant negative trends.

Decreasing streamflow volume in western Kansas has been supported by previous trend studies in this study area (Angelo, 1994; Jordan, 1982; Perry et al., 2004; Rasmussen & Perry, 2001). Irrigated agriculture is considered to be a primary factor in the shift from perennial to intermittent streams in the KRB, especially western Kansas (Aguilar, 2009; Perry et al., 2004). Many streams considered as perennial streams in the 1960s were reported as intermittent streams in 1990 (Perry et al., 2004). The western KRB has streams with lower flow (per unit area) compared to the eastern KRB because of the regional gradient in precipitation and soil characteristics. The western two thirds of the KRB typically has moderate to high permeability soils, and the eastern one third has lower permeability soils (U.S. Department of Agriculture, 1993). The KRB has an east-to-west annual precipitation gradient with less north-to-south variation. These differences lead to lower-unit-discharge streams in the western region and higher-unit-discharge streams in the eastern region. Along with the variation in unit discharge, variation in irrigation pumping, agricultural management practices, and soil and water conservation structures may have had a greater impact on High Plains streams and contributed to their greater decreasing trends in annual flow per unit area compared to the other KRB ecoregions (Figures 4 and 5).

Seasonal streamflow across the ecoregions demonstrated similar trends to annual streamflow (Figure 5). Again, the High Plains had significant negative trends at most streamgages in every season, and the Central Great Plains served as a transitional zone in which trends decreased in magnitude and became less significant from west to east. In the Central Great Plains, summer had the greatest number of streamgages (six) with significant negative trends (five at $p < .05$ and one at $p < .10$) compared to four (two at $p < .05$ and two at $p < .10$) in autumn, two ($p < .05$) in winter, and one ($p < .05$) in spring (Figure 5). For the eastern half of the KRB (map indices 1 and 14–34), no streamgages had significant annual trends (Figure 4, $p > .10$) and only four gages had significant seasonal trends (Figure 5), although a majority of those streamgages showed small positive seasonal trends during spring and small negative seasonal trends during summer and autumn.

The annual trends in streamflow (Figures 4 and 5) were not consistent with the annual trends in climatic variables (Figures 2 and 3). Ten of the 12 most westerly streamgages (map indices 2–13) had significant negative annual streamflow trends ($p < .05$; Figures 4 and 5). However, of the five most westerly climate stations, which spanned a similar geographic area, three showed significant positive annual precipitation trends and two showed significant negative annual temperature trends, both of which would generally support increasing streamflow (Figures 2 and 3). Consistent with Aguilar (2009), the

TABLE 2 Kendall tau and Sen's slope for trends in precipitation and temperature (water years 1962–2012)

Station name	COOP station ID	Period of record	Ecoregion	Precipitation		Temperature	
				Kendall tau	Sen's slope (mm/50 years)	Kendall tau	Sen's slope (°C/50 years)
Tribune	148235	1962–2012	High Plains	0.19**	1.97	0.07	0.70
St. Francis	147093	1962–2012	High Plains	−0.01	−0.15	−0.21**	−2.13
Colby	141699	1962–2012	High Plains	0.21**	2.18	0.19	2.00
McCook	255310	1962–2012	Central Great Plains	0.24**	2.44	0.01	0.15
Oberlin	145906	1962–2012	Central Great Plains	0.04	0.41	−0.26**	−2.70
Wakeeney	148495	1962–2012	Central Great Plains	0.04	0.37	0.32*	3.33
Phillipsburg	146378	1962–2012	Central Great Plains	−0.01	−0.11	−0.15**	−1.56
Minden	255565	1962–2012	Central Great Plains	n.d.	n.d.	−0.04	−0.44
Hays	143527	1962–2012	Central Great Plains	0.09	0.96	0.28*	2.92
Minneapolis	145363	1962–2012	Central Great Plains	0.17*	1.75	0.06	0.58
McPherson	145152	1962–2012	Central Great Plains	0.14	1.43	−0.10	−1.04
Manhattan	144972	1962–2012	Flint Hills	0.05	0.55	0.04	0.36
Beatrice	250622	1962–2011	Western Corn Belt	0.26**	2.70	−0.34**	−3.40
Horton	143810	1962–2012	Western Corn Belt	0.05	0.49	0.01	0.11
Lawrence	144559	1962–2012	Central Irregular Plains	−0.06	−0.60	−0.06	−0.65
Ottawa	146128	1962–2012	Central Irregular Plains	0.06	0.57	0.05	0.47
Atchison	140405	1962–2012	Central Irregular Plains	−0.03	−0.31	0.08	0.81

Note. n.d. = no data. Trend significance indicated at

**p* = .10 and

***p* = .05.

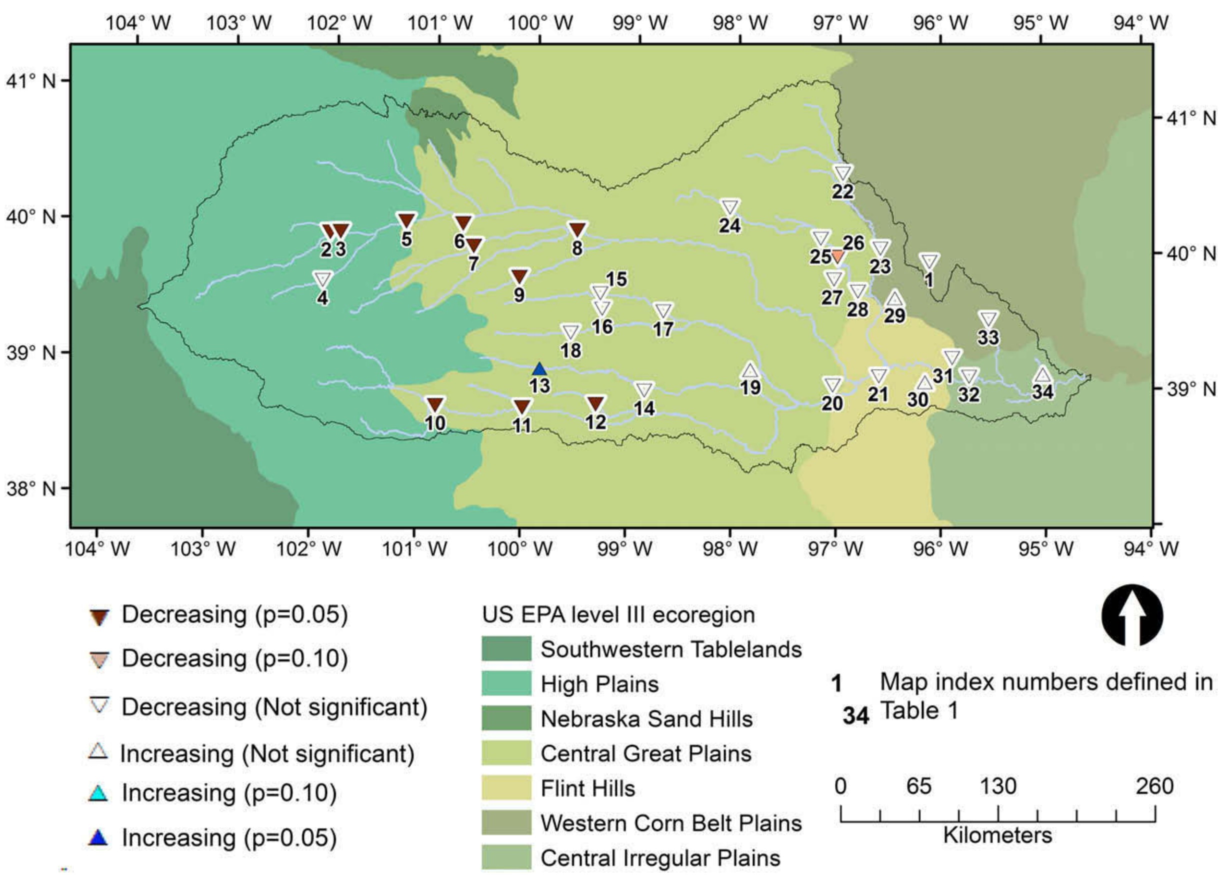

FIGURE 4 Trends (Mann–Kendall) in average annual streamflow per unit area at streamgages in the Kansas River basin (water years 1962–2012). Upward and downward pointing triangles represent increasing (blue) and decreasing (red) trends, respectively. Trend significance indicated by circles with dark fill (*p* = .05), light fill (*p* = .10), or no fill (n.s.)

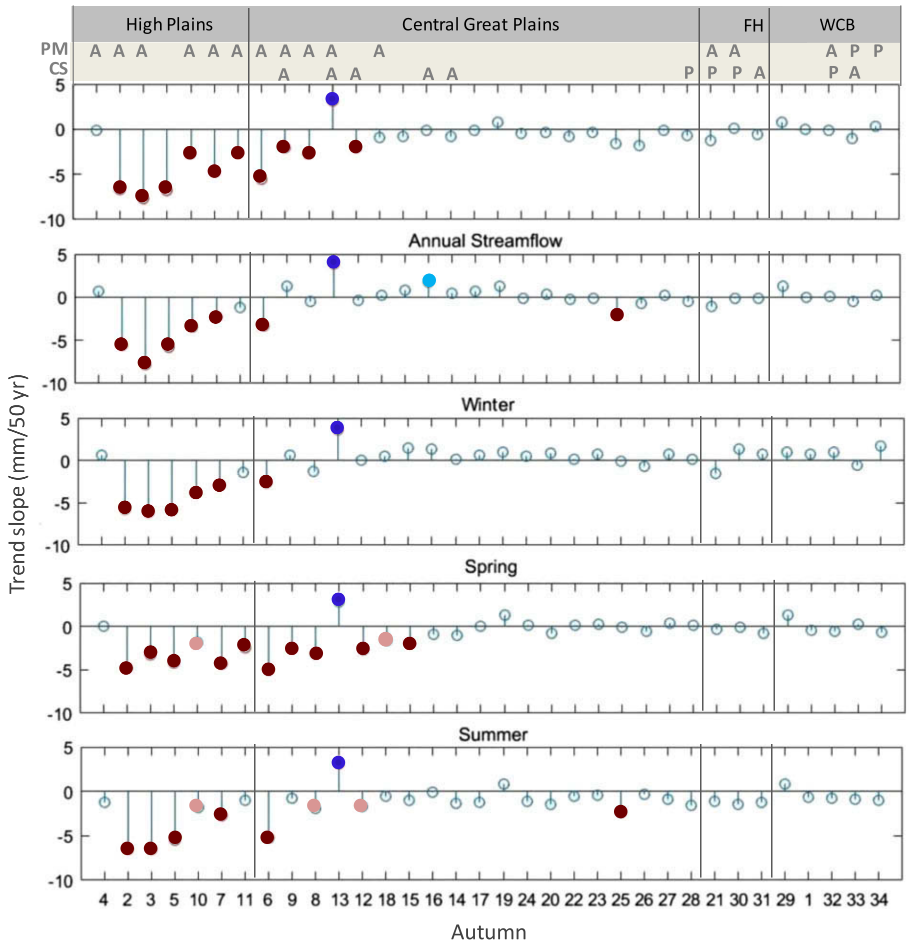

FIGURE 5 Trends (Sen's slope) for annual and seasonal streamflow at streamgages (map index numbers 1–34 defined in Table 1) in the Kansas River basin grouped by ecoregions: High Plains, Central Great Plains, Flint Hills (FH), and Western Corn Belt (WCB). Trend significance indicated by circles with dark fill (p = .05), light fill (p = .10), or no fill (n.s.). Plains Minnow (PM) or Common Shiner (CS) Presence (P) or Absence (A) (2000–2012) after being present historically (1860–1950) indicated for each map index basin

streamflow trends were more pronounced in the High Plains and western Central Great Plains streams (Figure 4), where the magnitude of annual precipitation was lower. These data suggest that changes in climate (precipitation and temperature) that would have led to increasing streamflow trends were more than offset by other factors that contributed to the observed decreasing streamflow trends. Among these factors could be greater consumptive water use (evapotranspiration) and greater alluvial aquifer withdraws from increased production intensity of agricultural crops (irrigation). This is consistent with documented trends of increasing irrigated corn and soybean acreages and decreasing irrigated grain sorghum acreage from 1972 to 2011 together with a rapid increase in Kansas irrigated acreage from the 1960s to 1980s, where an overwhelming majority of irrigation is in western Kansas (Rogers, Aguilar, Kisekka, Barnes, & Lamm, 2015).

3.3 | Extreme streamflow conditions trends

Trends for each streamgage were fairly consistent across all levels of flow minimums or maximums, but trends varied across streamgages and ecoregions (Figure 6). The High Plains streamgages showed negative trends in minimum flows (at least three of six were significant, $p < .05$). A majority of the Central Great Plains streamgages showed positive trends (six were significant, $p < .05$) for all duration levels of minimum flows (Figure 6).

Maximum-flow trends tended to decrease in magnitude from west to east in the watershed similar to annual and seasonal flows (Figure 5). Most streamgages in the High Plains showed significant ($p < .05$ or $p < .10$) negative trends for all levels of maximum flow, except Station 4 (negative, but not significant). Trends near zero (not significant) in maximum flows were observed in the eastern half of the KRB (map indices 1 and 14–34), except three streamgages located closer to central KRB (Figure 6). Pronounced negative trends in minimum- and maximum-flow IHAs in the High Plains and western Central Great Plains streams, which reflect the prevailing east-to-west gradient in precipitation and other biophysical factors, demonstrated a 50-year trend toward increasing drought in this region.

Five of the 12 most westerly streamgages in the KRB showed significant positive trends ($p < .05$) in number of zero-flow days (Figure 7). Each of these significant streamgages also showed negative (generally nonsignificant) trends in baseflow index (Figure 7). Conversely, in the Central Great Plains, 16 of 19 streamgages (four significant, $p < .05$) showed positive trends in baseflow index, with three of four significant streamgages also showing significant negative trends ($p < .05$) in zero-flow days. This prevalence of decreasing baseflow during dry periods

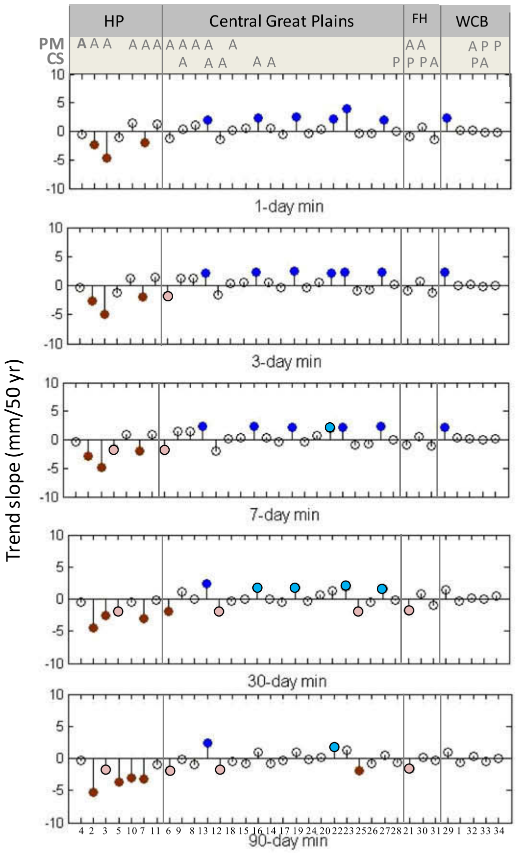

FIGURE 6 Trends (Sen's slope) in minimum flow (1- to 90-day min., left) and maximum flow (1- to 90-day max., right) at streamgages (map index numbers defined in Table 1) in the Kansas River basin grouped by ecoregions: High Plains (HP), Central Great Plains, Flint Hills (FH), and Western Corn Belt (WCB). Trend significance indicated by circles with dark fill (p = .05), light fill (p = .10), or no fill (n.s.). Plains Minnow (PM) or Common Shiner (CS) Presence (P) or Absence (A) (2000–2012) after being present historically (1860–1950) indicated for each map index basin

and increasing duration of dry periods in the High Plains and increasing baseflow with decreasing duration of dry periods in the Central Great Plains reveals a more complex interaction than can be described by climate (precipitation and temperature) alone. The Central Great Plains appears to be more consistent with the observed positive trends in precipitation in this region. Conversely, the High Plains has become droughtier despite generally increased rainfall and decreased temperature, potentially reflecting signatures of human hydrological alteration in this region, such as increasing groundwater use, decreasing groundwater level, and lower recharge of the western KRB.

3.4 | Streamflow timing trends

A negative trend in the CT of annual streamflow for a majority of streamgages (27 of 34 stations) indicates a shift in annual streamflow toward earlier in the year. Among those, four streamgages located in western Central Great Plains were significant at $p < .05$ and four were significant at $p < .10$ (Figure 7). Five (of seven) High Plains streamgages, one (of three) Flint Hills streamgages, and four (of five) Western Corn Belt streamgages also showed negative (nonsignificant) trends. The magnitudes of trend slope were up to −3.5 days/50 years (Figure 7). Several studies have found shifts toward earlier CT for snowmelt-dominated streams in North America (Clow, 2010; Dudley et al., 2017; Ryberg et al., 2015); for example, Stewart et al. (2005) found 3-day earlier CT for 73% (214) of gages in western North America, with about half of these being significant shifts. But snowmelt-dominated areas tend to fall west and north of the study region. Less work has focused on non-snowmelt-dominated streams of the Midwest United States. In the Missouri River Basin, Lins and Slack (2005) found no seasonal shifts in timing of streamflows during the 1940–1999 period but considerable interdecadal variability.

Figure 7 shows the date of annual minimum streamflow tends to be occurring later (positive trend up to 4 days/50 years), and the date of annual maximum streamflow tends to be occurring earlier in the year (negative trend to 4 days/50 years) for a majority of the streamgages studied. However, only eight of these streamgages (of 34) had significant (seven at $p < .05$ and one at $p < .10$) negative trends in date of annual maximum flow, and only three of these streamgages showed positive trends ($p < .05$) in date of annual minimum flow.

These shifts toward earlier median and maximum flows and later minimum flows may have meaningful impact on aquatic species migration, spawning, and other phenotypic behaviours.

3.5 | Streamflow frequency trends

Low-flow pulse (<25th percentile of daily flows) and high-flow pulse (>75th percentile of daily flows) events were analysed and displayed (Figure 8) by frequency (counts per year) and median duration (days) of high- and low-pulse events and rate and frequency of water condition changes. Some streamgages (7, 8, 13, and 21) were removed from

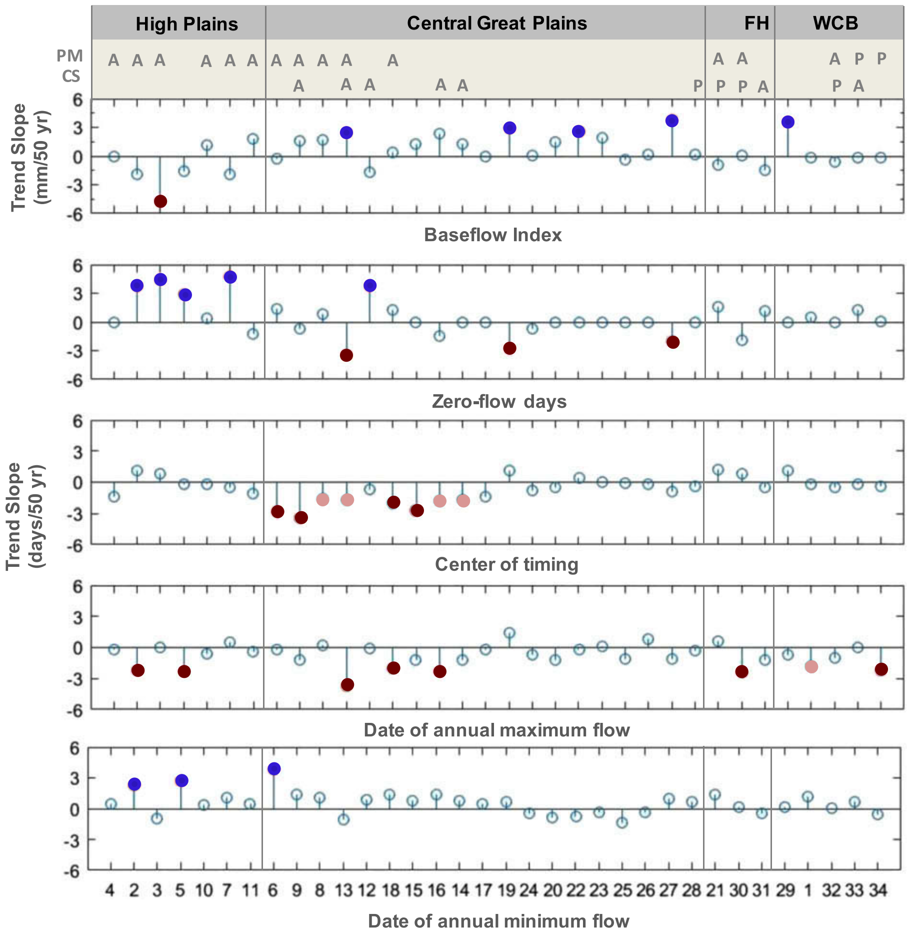

FIGURE 7 Trends (Sen's slope) in mean 7-day minimum baseflow, mean zero-flow days, centre of timing of annual streamflow, and the date of annual maximum and annual minimum flows at streamgages (map index numbers defined in Table 1) in the Kansas River basin grouped by ecoregions: High Plains, Central Great Plains, Flint Hills (FH), and Western Corn Belt (WCB). Trend significance indicated by circles with dark fill ($p = .05$), light fill ($p = .10$), or no fill (n.s.). Plains Minnow (PM) or Common Shiner (CS) Presence (P) or Absence (A) (2000–2012) after being present historically (1860–1950) indicated for each map index basin

these analyses because they had missing values and to avoid truncated pulses (The Nature Conservancy, 2009). Most streamgages in the High Plains and western Central Great Plains showed significant negative trends in the number and duration of high-flow pulses and significant positive trends in duration of low-flow pulses, but results for number of low-flow pulses were mixed for streamgages across ecoregions (Figure 8). A majority of streamgages showed negative trends in rise rates and positive trends in fall rates (Figure 8), with seven of the eight most westerly streamgages having significant trends ($p < .05$). Both trends toward decreasing rise rates and increasing fall rates indicated an increasing threat of drought incidence. Significant positive trends observed in the number of flow reversals over the study period showed greater variability across Central Great Plains, Flint Hills, and Western Corn Belt ecoregions (Figure 8).

Fewer lower duration and higher flow pulses, greater duration of low-flow pulses, smaller rise rates and greater fall rates, and increasing flow reversals all represent important shifts to streamflow timing and patterns that may impact critical seasonal stages in aquatic species life cycles.

3.6 | Relationship of climate and streamflow

The overall observed negative trend in annual average streamflow can be caused by climatic changes in rainfall and temperature patterns. The Pearson correlation coefficient (R) results show .63 correlation between annual average flow trends and annual average precipitation trends and .41 correlation between annual average flow trends and annual average temperature trends (Table 3). However, neither of these was significant ($p > .10$).

The absence of a significant correlation may be influenced by the relatively small sample size ($n = 8$) used in this study. As discussed above, however, it may also reflect influence of other anthropogenic factors that more than offset the effects of climatic drivers. Other than precipitation and temperature, groundwater depletion, terracing (particularly in western Kansas), and changes in land use and farming practices (such as contour farming, crop rotation, pasture improvement, and conservation reserve program) also can be related to the decreasing annual trend (Rasmussen & Perry, 2001). Correlation to these other factors was not assessed in this study.

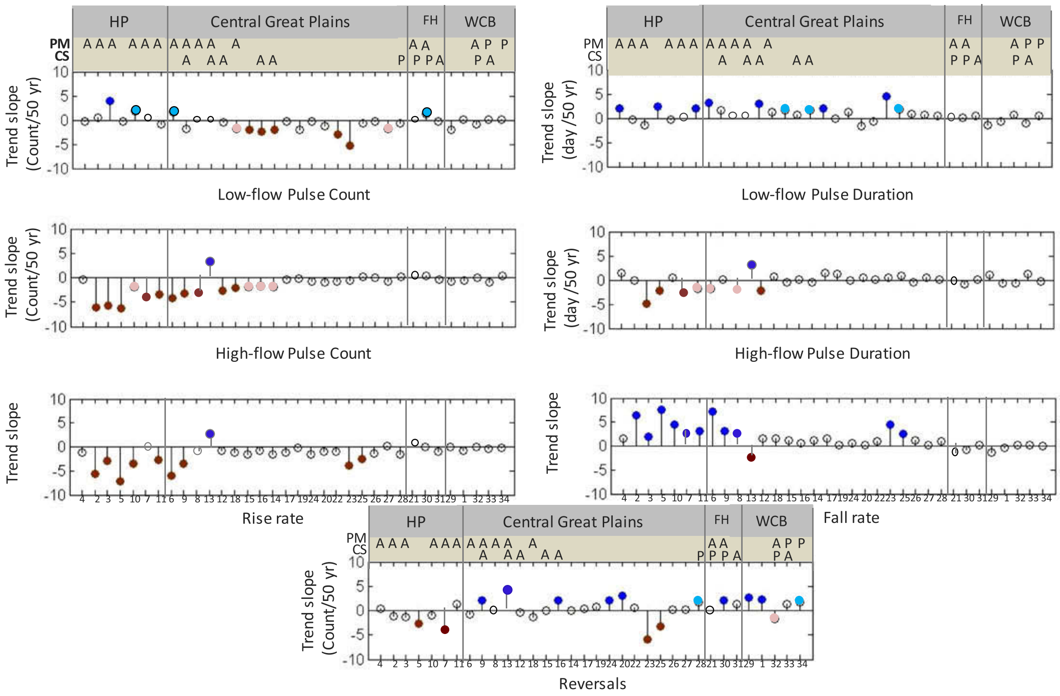

FIGURE 8 Trends (Sen's slope) in low-flow and high-flow pulse frequency (#) and duration, rise and fall rates, and reversals at streamgages (map index numbers defined in Table 1) in the Kansas River basin grouped by ecoregions: High Plains (HP), Central Great Plains, Flint Hills (FH), and Western Corn Belt (WCB). Trend significance indicated by circles with dark fill (p = .05), light fill (p = .10), or no fill (n.s.). Plains Minnow (PM) or Common Shiner (CS) Presence (P) or Absence (A) (2000–2012) after being present historically (1860–1950) indicated for each map index basin

TABLE 3 Trends (Sen's slope) in mean annual values for weather stations (precipitation and temperature) and corresponding U.S. Geological Survey (USGS) streamgages in the Kansas River basin and correlations (R) between flow and weather trends

Map index	USGS station code	Streamflow trend (mm/50 years)	Weather station	Precipitation trend (mm/50 years)	Temperature trend (°C/50 years)
7	06846500	−4.71**	St. Francis	−0.15	−2.13**
13	06866900	3.09**	Colby	2.18**	2.00**
14	06867000	−1.27	Wakeeney	0.37	3.33*
15	06871000	−0.83	Oberlin	0.41	−2.70**
23	06882000	−0.34	Beatrice	2.70**	−3.40**
30	06888500	0.05	Manhattan	0.55	0.36
34	06892000	0.31	Horton	0.49	0.11
34	06892000	0.31	Atchison	−0.31	0.81
Pearson correlation coefficient (R)				0.63	0.41

Note. Trend significance indicated at

*p = .10 and

**p = .05.

3.7 | Influence of streamflow on two native fish species

The Plains Minnow was historically present (1860–1950) at 16 sites in the KRB associated with the following streamgages and ecoregions (identified by map index, Table 1): High Plains Stations 2, 3, 4, 7, 10, and 11; Central Great Plains Stations 6, 8, 9, 13, and 18; Flint Hills Stations 21 and 30; and Western Corn Belt Stations 32, 33, and 34. These 16 sites showed a westerly bias, including 11 of the 13 most westerly streamgages (as shown on Figures 5–8) and just five streamgages in the eastern half of the KRB. Occurrence of the species at study sites shifted from present (1860–1950) to absent (2000–2012) at all but two sites (33 and 34); these two Present sites were the two most easterly sites in the KRB.

Common Shiner was historically present (1860–1950) at 11 sites in the KRB associated with the following streamgages and ecoregions (identified by map index, Table 1): Central Great Plains Stations 9, 12, 13, 14, 16, and 28; Flint Hills stations 21, 30, and 31; and Western Corn Belt stations 32 and 33. These 11 sites showed an easterly bias, including six of the nine most easterly streamgages (as shown on Figures 5–8) and just five streamgages in the western two thirds of the KRB, with none in the High Plains ecoregion. Occurrence of the species at study sites went from present (1860–1950) to absent (2000–2012) at all but four sites (21, 28, 30, and 32). All four of the Present sites were in the grouping of six easterly sites, and all five of the westerly locations were Absent sites.

Results demonstrated specific detrimental effects of flow-regime change on these two native fish species of Kansas (Table 4 and Figure 9). Both species were Absent from sites with greater decreasing trends of 1-day maximum flow ($p < .10$). Otherwise, change in species occurrence appeared to respond to different hydrological cues.

Plains Minnow occurrence generally responded negatively to greater decreasing trends (or shifts from increasing to decreasing trends) for many ecohydrological indices. Plains Minnow Absence

TABLE 4 Mean trends (Kendall tau, 1962–2012) of ecohydrological indicators for streamgages in the Kansas River basin at which Plains Minnow or Common Shiner were either “Absent” or “Present” (2000–2012) after being present historically (1860–1950)

	Plains Minnow			Common Shiner		
	Absent (tau) *n* = 14	Present (tau) *n* = 2	*p* value	Absent (tau) *n* = 7	Present (tau) *n* = 4	*p* value
Annual volume	−0.237	−0.033	0.095*	−0.044	−0.037	.933
Centre of timing of annual flow	−0.080	−0.028	0.216	−0.143	0.042	.025**
Mean spring daily discharge	−0.125	0.052	0.308	0.092	0.005	.333
Mean summer daily discharge	−0.190	−0.021	0.088*	−0.067	0.011	.357
Mean autumn daily discharge	−0.189	−0.094	0.179	−0.038	−0.069	.697
Mean winter daily discharge	−0.142	−0.014	0.150	0.091	−0.013	.211
October	−0.117	−0.037	0.175	0.016	−0.049	.278
November	−0.132	−0.095	0.640	0.007	−0.029	.519
December	−0.127	−0.014	0.165	0.060	0.003	.465
January	−0.089	−0.009	0.256	0.113	0.020	.355
February	−0.132	−0.023	0.168	0.057	−0.053	.185
March	−0.143	−0.004	0.234	0.061	−0.065	.075*
April	−0.086	0.057	0.102*	0.115	0.028	.343
May	−0.097	0.039	0.247	0.106	0.012	.220
June	−0.137	−0.013	0.151	0.015	0.002	.829
July	−0.113	0.020	0.012**	0.003	0.006	.965
August	−0.064	−0.012	0.216	0.011	0.015	.952
September	−0.137	−0.036	0.082*	−0.022	−0.042	.781
1-day min. flow	−0.019	−0.020	0.971	0.037	0.051	.859
3-day min. flow	−0.019	−0.003	0.721	0.052	0.057	.954
7-day min. flow	−0.025	0.002	0.554	0.053	0.049	.953
30-day min. flow	−0.063	0.028	0.105*	0.049	0.013	.604
90-day min. flow	−0.114	−0.026	0.147	0.002	−0.027	.707
1-day max. flow	−0.201	−0.036	0.081*	−0.110	0.035	.095*
3-day max. flow	−0.220	−0.029	0.109	−0.104	−0.011	.255
7-day max. flow	−0.228	−0.054	0.208	−0.103	−0.034	.399
30-day max. flow	−0.237	−0.069	0.166	−0.094	−0.055	.616
90-day max. flow	−0.237	−0.037	0.034**	−0.065	−0.073	.914
Zero-flow days	0.079	0.025	0.433	−0.032	0.048	.351
Baseflow	−0.002	−0.017	0.728	0.067	0.066	.996
Date of min. flow	0.077	0.006	0.412	0.049	0.052	.932
Date of max. flow	−0.085	−0.104	0.890	−0.147	−0.031	.090*
Low-flow pulse count	0.024	0.005	0.636	−0.090	−0.087	.953
Low-flow pulse duration	0.086	−0.035	0.330	0.098	−0.005	.211
High-flow pulse count	−0.220	−0.029	0.109	−0.104	−0.010	.255
High-flow pulse duration	−0.069	0.050	0.339	0.022	0.003	.785
Rise rate	−0.171	−0.025	0.034**	−0.061	−0.034	.732
Fall rate	0.202	0.002	0.015**	0.054	−0.034	.270
Reversals	−0.016	0.160	0.006**	0.152	0.064	.454

Note. Trend significance indicated at

*$p = .10$ and

**$p = .05$.

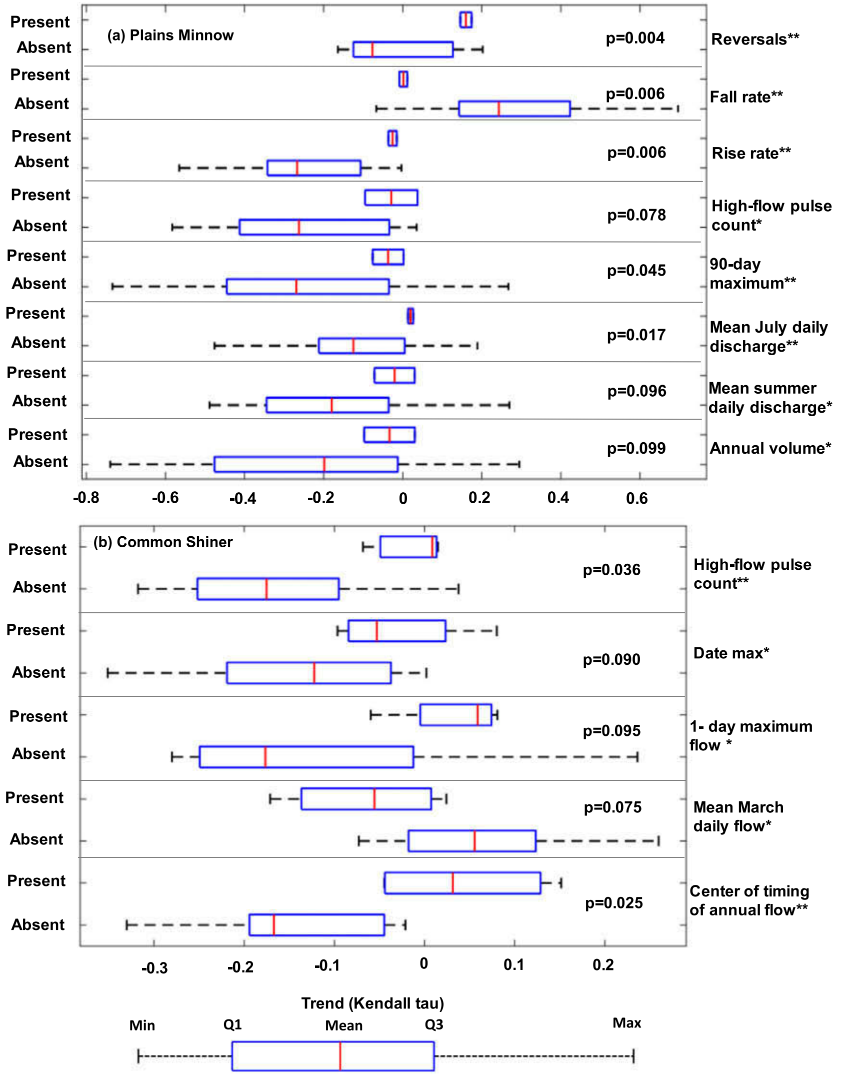

FIGURE 9 Comparison of trends (Kendall tau, 1962–2012) in significant ecohydrological indicators at 16 streamgages in the Kansas River basin at which (a) Plains Minnow or (b) Common Shiner was either "Present" or "Absent" (2000–2012) after being present historically (1860–1950). Significant differences (paired *t* test) between Present and Absent groups noted at $p < 0.10$* and $p < 0.05$**

was significantly (or marginally significantly) related to streamflow records having greater decreasing trends of annual volume ($p = .095$), seasonal flow in summer ($p = .088$), monthly flow in April ($p = .102$), in July ($p = .102$), and in September ($p = .082$); 30-day minimum flow ($p = .105$) and 1-day ($p = .081$), 3-day ($p = .109$), 90-day ($p = .034$) maximum flows; rise rate ($p = .034$) and reversals ($p = .006$); and greater increasing trends in fall rate ($p = .015$; Table 4 and Figure 9). The decreasing trends indicate declining flows overall (annual volume), at critical times of the year (summer in general and spanning the months of April through September), and for critical hydrological periods (sustained minimum flow or maximum flow periods).

The correlations observed between the shifts in Plains Minnow occurrence and ecohydrological indices do not demonstrate causal relationships, but the observed correlations are generally supported by important ecological response characteristics specific to Plains Minnow. Decreasing flow trends and species disappearance can be related to unsuccessful spawning events. Spawning for Plains Minnow is known to occur in the summer period (Distler et al., 2014) with higher flows sufficient to maintain buoyancy of their nonadhesive, semibuoyant eggs (Taylor & Eberle, 2014). Because Plains Minnow eggs are semibuoyant, there must be a sufficient flow to keep eggs from sinking to the bottom and being covered with substrate. Where there is insufficient water, eggs could be damaged and killed or dried due to extreme temperature (Taylor & Eberle, 2014). In the KRB, higher flows generally occur in the summer season, which is consistent with the observed Absent response to decreasing flows, particularly for ecohydrological indices that describe trends in summer, maximum-flow periods, and high-flow pulse frequency (Table 4). Decreasing trends in rise rates and reversals and increasing trends in fall rates (Table 4) all describe a condition having more gradual changes in and less frequent alternations between the rising limbs and falling limbs of the streamflow hydrograph, which would also be detrimental to maintaining higher flow conditions suitable for suspension of semibuoyant eggs. It may also be important that the decreasing-flow trends extend from April through September, so even though Plains Minnow can have multiple spawns (Taylor & Eberle, 2014), this resilient characteristic would not be adequate to overcome a persistent decreased-flow stressor that spans the entire high-flow spawning period.

Another possible ecological response of Plains Minnow consistent with the observed decreasing ecohydrological index trends could be changes to the hyporheic zone, where shallow groundwater and surface water mix beneath and alongside a stream bed. This zone is an important region of biogeochemical cycling and biological activity. It also serves to regulate temperature, especially in small streams, and acts as a natural treatment system. The Plains Minnow is found in perennial streams with shallow, braided flow over broad beds of shifting sand, where they feed on diatoms and other algae. When there are no seasonal scouring-level discharges and diminished summer flows, those diatoms and algae may be eliminated due to insufficient water to maintain the hyporheic zone. This change has been previously linked to declines in Plains Minnow (Distler et al., 2014) and is consistent with the significant declines in 30-day minimum flow trends and consistent (but nonsignificant) declines in baseflow and increases in zero-flow days, low-flow pulses, and other (particularly longer duration) minimum-flow periods (Table 4).

Similar results were reported by Gido et al. (2013), who found native fish in natural flow regimes of the southwest United States responded positively to higher mean spring flows and baseflow index, slightly positively to high pulse count, and negatively to summer discharge variability. In a study of subtropical rivers in Australia, Arthington et al. (2014) also found that high-flow pulse count and mean daily flows and their variability were important in structuring fish assemblages; other important antecedent flow conditions were baseflow, number of zero-flow days, magnitude of the 1-year annual return interval flood, and the constancy and predictability of monthly flows.

Common Shiner occurrence demonstrated a significant response to just four ecohydrologic indices. Common Shiner Absence was significantly related to streamflow records having greater decreasing trends (i.e., toward earlier in the WY) of CT (p = .025) and date of maximum flow (p = .090), decreasing trends of 1-day maximum flow (p = .095), and increasing trends in March monthly flow (p = .075).

Again, although the correlations observed between the shifts in Common Shiner occurrence and ecohydrological indices do not demonstrate causal relationships, the results suggest several important ecological response characteristics specific to Common Shiner that warrant further study. Common Shiner normally spawns from late April to early July with peaks in mid-May (Cathcart, 2014). They use already-built nests by other species, or the male shiner excavates pits in shallow riffles. If there is insufficient flow to form riffles, the spawning events of Common Shiner will not be successful. This does not appear to be the case in the KRB. Sites consistently (10 of 12 months, September through June) had weakly positive or negative monthly trends (−0.065 to 0.048 mm/50 years) for Present sites but stronger increasing trends (−0.022 to 0.115 mm/50 years) for Absent sites, increasing by a monthly average of 0.07 mm/50 years. Though Common Shiner reside in riffle zones, during droughts, they survive in isolated pools (Cathcart, 2014). The increasing trends at Absent sites relative to Present sites may result in a decreasing intermittency of these streams that reduces the number and severity of periods when they otherwise would seek refuge in isolated pools, which may result in conditions that place Common Shiner at a competitive disadvantage. Although plausible, this result is speculative and would require more detailed study for confirmation.

Several other trend comparisons present a consistent story, though they did not attain statistical significance. Mean summer discharge trends increased and mean winter and spring discharge trends decreased for the Absent sites relative to Present sites. Response to mean spring flow trends was opposite to that suggested by Gido et al. (2013) for the southwest United States, suggesting substantial interspecies differences, even within closely proximal geographic regions. The general (nonsignificant) trends of decreasing zero-flow days and increasing low-flow pulse durations at Absent sites relative to Present sites may provide support for the decreasing intermittency suggested by the monthly flow trends. Finally, Common Shiner was Absent in streams with greater increasing mean spring discharge trends in 2000–2012. As Common Shiner is a silt-intolerant species, flow-related increasing turbidity may be a possible reason for their absence in streams with increasing trends in spring flow (Cathcart, 2014). Although these differences in trends between Absent and Present sites were "small" and not enough to show statistically significant differences (Table 4 and Figure 9), even small-magnitude trends might be extremely rapid in an ecological sense to the extent that species could not develop an adequate survival response or the environmental change exceeds the phenotypic plasticity of the species. Again, this result is not directly supported by evidence from this study and would require further analysis into the species-specific ecological impacts from the observed hydrological trends.

In addition to streamflow alteration, other anthropogenic stressors, including soil erosion and fertilizer and agrochemical runoff from increasing row-crop agriculture production (beginning in 1880), habitat fragmentation caused by impoundments (beginning in the 1950s) and reduced return flow caused by groundwater withdrawal (beginning in the 1960s), could also play a role in fish distribution. However, the effects of those factors were not tested in this study.

4 | CONCLUSION

Trends of WRIs and IHAs have been observed for KRB streamgages using 50-year streamflow records. Across the entire KRB, a negative trend is evident for annual (29 of 34 stations), summer (23 of 34 stations), and autumn (31 of 34 stations) mean streamflow; 30-day (21 of 34 stations) and 90-day (24 of 34 stations) minimum streamflows; and 1-day (25 of 34 stations), 3-day (27 of 34 stations), 7-day (29 of 34 stations), 30-day (29 of 34 stations), and 90-day (29 of 34 stations) maximum streamflows. Streamflow trend magnitude, both annually and seasonally, tended to decrease from west to east in the watershed. These results show that there are ongoing adverse hydrological changes in the KRB. There were regional differences in ecohydrological index trends, but these did not appear to be strongly tied to the U.S. EPA Level III ecoregions. Rather, other anthropogenic factors, likely increased irrigation withdrawals in the western KRB, reduced annual and seasonal streamflow discharges, maximum and minimum flows, and high-flow counts and hydrographic flashiness.

Mean annual precipitation showed an increasing trend (12 of 16 stations), and mean annual temperature showed a mix of increasing trends (10 of 17 stations) and decreasing trends (seven of 17 stations). The Pearson correlation coefficient (R) results showed .63 correlation between annual average flow trends and annual average precipitation trends and .41 correlation between annual average flow trends and annual average temperature trends, though neither correlation was significant, suggesting a substantial influence of nonclimatic drivers on streamflow trends.

The shift in occurrence of two native fish species (Plains Minnow [*Hybognathus placitus*] and Common Shiner [*Luxilus cornutus*]) from present (1860–1950) to absent (2000–2012) was significantly related to negative trends of 1-day maximum flows (both species) and a number of ecohydrological indices that relate to reduced spawning-season flows for Plains Minnow and shifting annual flow timing and increased flow intermittency for Common Shiner. Both species were Absent for all sites in the western half of the KRB. Negative trends in minimum and maximum flows for Absent sites may suggest an additional stressor, especially in the High Plains ecoregion. In the eastern half of the KRB, sites and conditions that resulted in Absent response differed dramatically for the two species studied. In general, but particularly for Plains Minnow, increasing trends in fall rates and low-flow pulse duration and decreasing trends in high-flow pulse count and duration for Absent sites show higher drought potential and increasingly unsuitable conditions for spawning, migration, and survival for aquatic organisms in this region.

The demonstrated detrimental effect of flow-regime change on native fish species of Kansas may suggest factors that could be targeted in restoration activities. Factors that increase the number of high-flow pulse events (e.g., dam removal) or increase mean summer flows (e.g., decreased alluvial aquifer pumping) would reverse the trends of significant streamflow stressors and could improve conditions for aquatic species.

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