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HYDROLOGIC VARIABILITY INFLUENCES LOCAL PROBABILITY OF PALLID STURGEON OCCURRENCE IN A MISSOURI RIVER TRIBUTARY

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ABSTRACT

A river's flow regime creates and maintains spatial variability in habitat and dictates the distribution and abundance of riverine fishes. Changes to patterns of natural hydrologic variation and disturbance create novel flow conditions and may influence distribution of native fishes. We examined local and regional-scale factors that influenced the presence of pallid sturgeon *Scaphirhynchus albus* in the Platte River, a large tributary to the Missouri River in Nebraska, USA. Daily river discharge, diel flow variability, season and location in the study area were the most supported variables in logistic regression models explaining pallid sturgeon distribution. The probability of pallid sturgeon occurrence was greatest during periods of high discharge (>90th percentile flows) in the spring and fall. Pallid sturgeon occurrence was always lower when variability in diel flow patterns was high (i.e. hydropeaking). Our results indicate that pallid sturgeon use of the lower Platte River was strongly tied to the flow regime. Therefore, the lower Platte River may provide an opportunity to preserve and restore sturgeon and possibly other large-river fishes through appropriate water management strategies. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: hydrology; sturgeon; distribution; tributary; flow

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INTRODUCTION

A river's flow regime creates and maintains spatial variability in habitat and dictates the distribution and abundance of riverine fishes across a river system (Poff and Allan, 1995; Poff *et al.,* 1997; Pusey *et al.,* 2000; among others). A single river can provide episodic, seasonal and persistent types of habitat based on the natural variation in frequency, timing, magnitude, duration and rate of change in seasonal and annual flows (Southwood, 1988; Pegg and Pierce, 2002a; Kennard *et al*., 2007). Connectivity among habitat types influences local colonization and extinction of fishes across the landscape. The diversity of habitat types created and maintained by hydrologic variability facilitates the distribution of species within a river system by promoting the evolution of physical and behavioural traits used by riverine fishes to carry out specific life-history strategies (e.g. reproduction; Poff and Allan, 1995).

Just as the natural flow regime is directly involved in determining fish assemblages in rivers and streams, temporal patterns in annual flow variability are related to population dynamics, reproduction and recruitment of native fishes (Bunn and Arthington, 2002). Many characteristics of the life cycle of a particular species of fish are linked to the flow regime. For example, spawning behaviour (i.e. reproduction) in some lotic species is triggered by peak discharge events during the spring (DeLonay *et al*., 2007; Goodman *et al*., 2012). During peak flows, lotic species make upstream migrations allowing sufficient distance for larvae to drift back downstream and recruit to the population (Leibold *et al*., 2004). Peak flows also allow lateral expansion into the floodplain, providing nursery habitats for young and allochthonous energy inputs for growth and survival (Poff *et al*., 1997; Bunn and Arthington, 2002; Kennard *et al*., 2007). Conversely, extended low-flow periods can be important for fishes that are restricted to spawning in the main channel. Concentrated prey is abundant, providing energy for the successful transition from endogenous to exogenous feeding (i.e. 'low-flow recruitment hypothesis'; Humphries *et al*., 1999). Ultimately, a river's natural flow regime, coupled with other environmental conditions (e.g. temperature), creates optimal situations for a variety of life stages or strategies that have adapted to these dynamic environments (Humphries *et al*., 2013).

Changes to a river's natural flow regime alter the established patterns of natural hydrologic variation and disturbance and create novel conditions to which native fishes may be poorly adapted (Poff *et al*., 1997; Malmqvist and Rundle, 2002). Extreme daily variations, such as hydropeaking events produced by power generation, have no natural equivalent, and many aquatic populations experience high mortality rates because of stress from washout or from being stranded during periods of low flow (Nagrodski *et al*., 2012; Richards *et al*.,

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2013). Similarly, streams with low variability in flow have very different fish assemblages than streams with high variability (Meador and Carlisle, 2012). In artificially fluctuating environments, riverine species with specialized adaptations are typically replaced by generalist species that can tolerate frequent and large fluctuations in flow (Poff and Allan, 1995; Poff *et al*., 1997; Pusey *et al*., 2000; Pegg and Pierce, 2002b). Many studies have noted shifts in native fish assemblages following modifications to the natural flow regime. Meador and Carlisle (2012) found a greater loss of native species from sites that had reduced natural streamflow variability, and there was a strong relation with the severity of streamflow alterations to the probability of native species impairment. Mims and Olden (2012) examined fish assemblage alterations in response to modified flow regimes by large dams. Water management operations using dams can create a high degree of flow constancy (i.e. reduced natural variability) and such a change can lead to a shift in life-history strategies. Fish assemblages downstream of dams had a greater proportion of equilibrium species (common in more stable and predictable environments) and a lesser proportion of opportunistic species (common in an environment with unpredictable change; Mims and Olden, 2012).

Identifying aspects of the flow regime that are conducive or detrimental to native life-history strategies can be an important component for establishing management objectives aimed at enhancing or conserving riverine species (Meador and Carlisle, 2012; Mims and Olden, 2012). However, main-stem large-river systems are permanently altered because of dams and channelization structures and provide little opportunity for flow manipulation to mimic a premodified flow regime. Large tributary streams have a lower degree of physical alteration and may provide an opportunity to enhance conservation of large riverine species, as most large-river species tend to use at least some areas of tributaries as well as main stems (Neely *et al*., 2009; Pracheil *et al*., 2009; Goodman *et al*., 2012; Pracheil *et al*., 2013).

Sturgeon and paddlefish (order Acipenseriformes) embody an extant group of obligate riverine fishes that have been recognized as the most endangered taxon on Earth by the International Union for Conservation of Nature (Lenhardt *et al*., 2006). Sturgeon represent a lineage dating back to the Lower Jurassic period (200 million years; Pikitch *et al*., 2005) and have evolved life-history traits and strategies that are well suited for stochastic riverine environments. The specialized traits (e.g. morphology, long life expectancy and intermittent spawning) that are advantageous for life in variable, yet predictable, conditions in river systems also make sturgeon highly susceptible to anthropogenic disturbances. Although it is often postulated, few studies have documented how physical or flow alterations have negatively influenced sturgeon populations, particularly North American sturgeon. Recent work by Goodman *et al*.

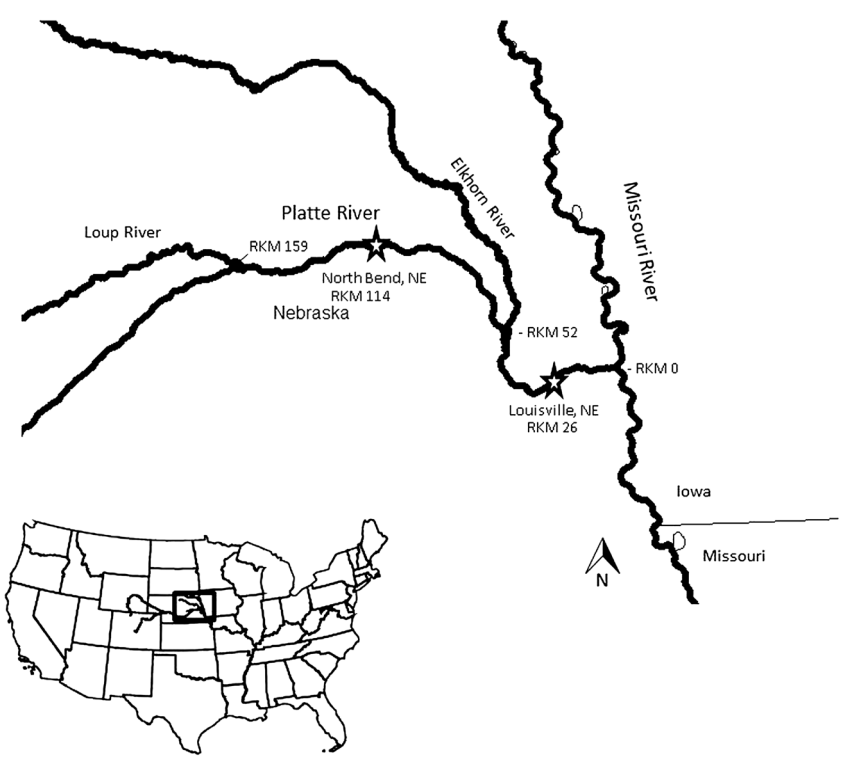

Figure 1. Map of the lower Platte River study area

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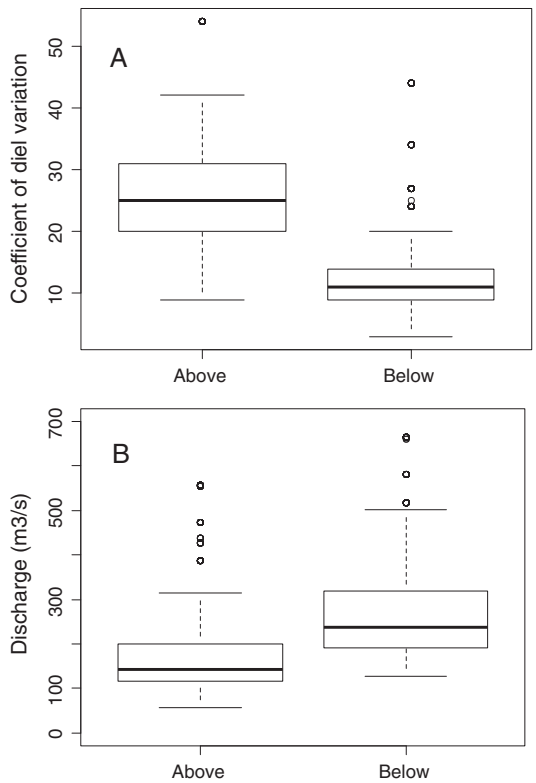

Figure 2. Coefficient of diel variation (A) and mean daily discharge (B) for areas above and below the Elkhorn River confluence in the lower Platte River, Nebraska. Discharge data were recorded from USGS gauging stations at Louisville, NE (Gage 06805500) and North Bend, NE (Gage 06796000). The horizontal line of the box plot is the median, the ends of the box are the upper and lower quartiles, and the vertical lines are the full range of values in the data excluding outliers (i.e. circles)

(2012) showed a positive relation between discharge and shovelnose sturgeon *Scaphirhynchus platorynchus* occurrence for spawning in a regulated tributary of the Missouri River. Increased discharge releases from a dam when the temperature regime was suitable for spawning resulted in successful reproduction, whereas no reproduction was evident in years that lacked a spring pulse (Goodman *et al*., 2012). An increase in discharge during the spring has been shown to be advantageous for spawning, but how water management throughout the remainder of the year influences the distribution and abundance of sturgeon species that inhabit regulated rivers or their free-flowing tributaries is unknown.

Our goal is to gain an understanding of the effects that river regulation has on distribution (i.e. presence) of a large-bodied river specialist, pallid sturgeon *Scaphirhynchus albus*, in an unconstrained tributary of the Missouri River. Pallid sturgeon are an obligate fluvial specialist that are predominantly found throughout the main stem of the Missouri and Mississippi rivers and portions of several large tributaries. Telemetry studies have shed light on seasonal habitat use of pallid sturgeon and have linked usage to site-specific temperature and flow characteristics (Bramblett and White, 2001; Hurley *et al*., 2004; Jordan *et al*., 2006), but the specific environmental conditions (i.e. discharge and temperature regimes) that dictate the presence of river sturgeon are unknown. Thus, the objective of our study was to determine how probabilities of pallid sturgeon captures were influenced by river discharge, variability in daily discharge patterns and capture-site characteristics (e.g. turbidity and temperature).

STUDY AREA

The study was conducted on the lower Platte River, Nebraska. The Platte River is a highly braided system that forms wide, shallow channels as it crosses the Great Plains. The lower Platte River, defined as the lower most 159 km of river, is undammed and has had very few physical anthropogenic alterations (e.g. channelization structures or bank armouring). The lower Platte River has some semblance of its historic characteristics (i.e. braided channels and sandbars) but is subject to severe fluctuations in river discharge (Holland and Peters, 1989). Water withdrawal and diversion for hydropower, irrigation and municipalities create large oscillations in the hydrograph over a variety of temporal scales (i.e. daily and seasonally; Galat *et al*., 2005). The lower Platte River has two hydrologically distinct areas (hereafter referred to as segments) bisected by a large tributary (Elkhorn River; Figure 1). The Platte River below the Elkhorn River confluence [river kilometre (rkm) 0–52] is characterized by continuous but variable flows year round with a significant portion of the base flow coming from the groundwater-fed Elkhorn River (Galat *et al*., 2005). Above the Elkhorn River confluence (rkm 52–159) also has continuous flow; however, diel fluctuations in flow are apparent because of the production of hydroelectricity in the Loup River Power Canal (Figure 2).

METHODS

Data collection

Pallid sturgeon were collected during 2009–2011 in the lower Platte River at randomly selected sites (i.e. 1-km reaches) within each river segment. We selected 40 sites from each segment and re-randomized each season. Seasons were delineated as spring (March–May), summer (June–August) and fall (September–November). Fish collection methods followed Peters and Parham (2008) and Drobish (2008) for drifted trammel nets and trotline sampling. Seven trammel nets and trotlines (i.e. 14 total sub-samples) were deployed at each site. Trammel nets were actively drifted in suitable

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Table I. Candidate models, Akaike's information criterion (AIC), number of parameters (k), increase over the lowest AIC (ΔAIC) and Akaike model weight (w_i) for models that we used to predict the occurrence of pallid sturgeon throughout the lower Platte River during 2009–2011

Candidate models	AIC	k	ΔAIC	w
presence ~ SEA*DISC + RKM	−4138.05	8	0.00	0.47
presence ~ SEA*DISC + CV + RKM	−4136.79	9	1.26	0.25
presence ~ SEA*DISC*CV + RKM	−4136.58	14	1.47	0.23
presence ~ SEA*DISC + CV	−4133.58	8	4.46	0.05
presence ~ SEA*DISC	−4118.53	7	19.52	0
presence ~ SEA*CV + RKM	−4114.84	8	23.20	0
presence ~ SEA*CV + DISC + RKM	−4113.13	9	24.92	0
presence ~ SEA*CV + DISC	−4104.55	8	33.50	0
presence ~ SEA*CV	−4104.08	7	33.97	0
presence ~ RKM*CV	−4098.30	5	39.75	0
presence ~ RKM	−4094.76	3	43.29	0
presence ~ DISC*CV + RKM	−4094.56	6	43.49	0
presence ~ RKM*DISC	−4093.22	5	44.83	0
presence ~ DISC*CV + SEA	−4092.37	7	45.68	0
presence ~ DISC*CV	−4084.45	5	53.60	0
presence ~ CV	−4081.41	3	56.64	0
presence ~ YEAR	−4071.06	4	66.99	0
presence ~ SEA	−4051.58	4	86.47	0
presence ~ RKM*CV + TEMP	−3783.41	6	354.64	0
presence ~ TEMP	−3724.23	3	413.82	0
presence ~ SEA*RKM*CV + TEMP + TURB + VEL	241.29	16	4379.34	0
presence ~ VEL	322.09	3	4460.14	0
presence ~ TURB	327.72	3	4465.77	0

SEA, sampling season; DISC, mean daily discharge (m^3 s); CV, coefficient of diel variation; RKM, river kilometre; TEMP, temperature (°C); TURB, turbidity (ntu); VEL, mean column velocity (ft^3 s).

habitat (i.e. where gear could properly be deployed) at each site for approximately 100 m during daylight. Trotlines baited with nightcrawlers *Lumbricus terrestris* were stationary and fished at each site overnight, not to exceed a 24-h period. Trammel nets were constructed from monofilament nylon with a depth of 1.8 m and length of 38.1 m. The outside mesh panels were 15.0-cm bar mesh and inside panels were 2.5-cm bar mesh. Trotlines consisted of a 30.5-m main line with 20, 3/0 O'Shaughnessy hooks attached at 1.5-m intervals.

Water temperature (°C) was recorded for every sub-sample. Additional habitat data were collected from 30% of all sub-samples, selected at random, for each site (i.e. two of seven sub-samples), as outlined in Drobish (2008). Variables used to describe these local-scale habitat parameters include mean water column velocity ($m\,s^{-1}$), turbidity (ntu) and conductivity ($\mu S\,m^{-1}$). In addition to randomized habitat collections, these parameters were also recorded whenever a pallid sturgeon was captured, so that habitat variables were always collected when the target species was captured. We used daily discharge data from the US Geological Survey (USGS) at North Bend, Nebraska (above the Elkhorn River confluence; Gage 0679600) and Louisville, Nebraska (below the Elkhorn River confluence; Gage 06805500) to describe how hydrological factors might influence pallid sturgeon occurrence. Sub-daily flow data (i.e. 15-min readings) were used to calculate a coefficient of diel variation (CV) to depict the diel variation in discharge.

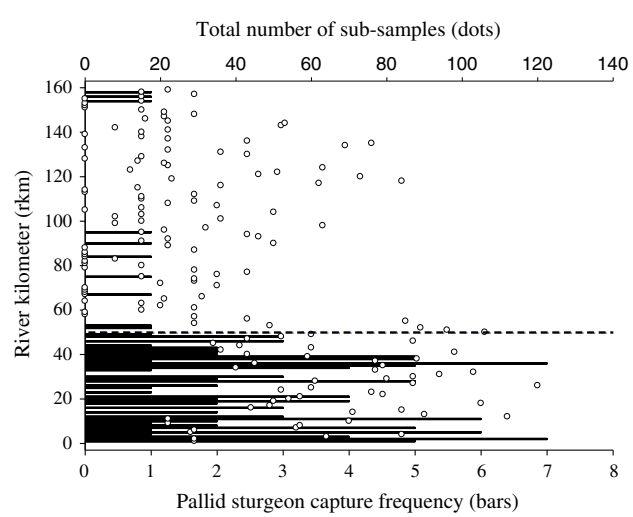

Figure 3. Distribution of pallid sturgeon captures ($n = 125$; represented by bars) by river kilometre in randomly selected sites of the Platte River, Nebraska, during the spring, summer, and fall sampling season in 2009–2011. Also displayed is the total number of sub-samples (dots) performed during the study period. The dashed line indicates the Elkhorn river confluence (rkm 52)

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Data analyses

We fit generalized linear models to our binomial capture data (0 = failure, 1 = success) using a logit link function (R Development Core Team, 2012). We used site-specific habitat parameters and river discharge characteristics from two USGS gauging stations within the respective segments to predict the local probability of pallid sturgeon occurrence (i.e. at the site level). Continuous variables included mean daily discharge, CV, rkm, temperature, turbidity and mean water column velocity. The effect of sampling seasons was treated as a categorical variable. We constructed 22 *a priori* candidate models (Table I) and used an information theoretic approach [Akaike's information criterion (AIC)] to rank candidate models and to account for the model uncertainty. The candidate model with the lowest AIC was selected as the best model. To rank the remaining models, we calculated the ΔAIC value where the difference of the best model AIC score and the AIC of the remaining models was $\Delta i = (\mathrm{AIC}_i - \mathrm{AIC}_{min})$. Akaike weights ($w_i$) were computed for each model to help gauge the relative support for each model among the model set (Burnham and Anderson, 2002).

RESULTS

We captured 125 pallid sturgeon of varying sizes (242–1,045 mm) and ages (age 1–age 14+) in 4695 sampling gear deployments during 2009–2011. Refer to Hamel *et al*. (2014) for a complete description of capture details. Pallid sturgeon were captured throughout a wide range of habitats and were found throughout the entire study area during all sampling seasons. However, pallid sturgeon were observed in higher frequency in locations below the Elkhorn River confluence (Figure 3) and during the spring ($n = 46$) and fall ($n = 61$) sampling seasons.

A model that contained the effects of sampling season, river discharge and location in the study area (rkm) was the best candidate model, having a weight of 0.47 (Table I). There was a longitudinal effect of the probability of pallid sturgeon occurrence, with the highest probability occurring near the mouth of the river and a decreasing probability of occurrence moving upstream (rkm: -0.02 ± 0.004). Inclusion of the CV parameter into the top model accounted for 25% of the remaining weight (Table I). The remaining model that carried a substantial portion of the total weight (23%) was a less parsimonious variation of these two models, with a three-way interaction between season, river discharge and CV. We chose not to model-average our predictions because of the cumulative weights of these similarly constructed models (Burnham and Anderson, 2002).

We used our top two parsimonious models to make inferences on probabilities of pallid sturgeon occurrence in the lower Platte River. We evaluated the effects of low, medium and high discharge values (i.e. 10th, median and 90th percentile) for each sampling season to assess how probabilities of pallid sturgeon occurrence changed throughout the lower Platte River under differing flow conditions. Our first model predicted that the greatest probability of pallid sturgeon occurrence during the spring and fall occurred under a high discharge regime (i.e. 90th percentile in flows; Table II). This was particularly true during the fall when the highest overall probability of pallid sturgeon occurrence was observed (Figure 4). Occurrence of pallid sturgeon during the summer was greatest under periods of low flow. Using our second model, we examined how low and high diel flow variability (i.e. 10th and 90th percentile in CV) influenced pallid sturgeon occurrence under all three discharge regimes in each sampling season. A low CV always predicted a higher probability of pallid sturgeon occurrence, regardless of discharge level or sampling season (Figure 5).

Table II. Probability of pallid sturgeon occurrence at varying levels of discharge during the spring, summer and fall seasons

		River kilometre (RKM)			
Season	Discharge percentiles	RKM 1	RKM 52	RKM 105	RKM 159
Spring	10th percentile	0.054	0.020	0.007	0.002
	Median	0.062	0.023	0.008	0.003
	90th percentile	0.098	0.038	0.013	0.005
Summer	10th percentile	0.049	0.018	0.006	0.002
	Median	0.039	0.014	0.005	0.002
	90th percentile	0.017	0.006	0.002	0.001
Fall	10th percentile	0.040	0.015	0.002	0.002
	Median	0.077	0.029	0.005	0.003
	90th percentile	0.456	0.231	0.011	0.034

Probabilities were generated for four evenly spaced locations throughout the lower Platte River.

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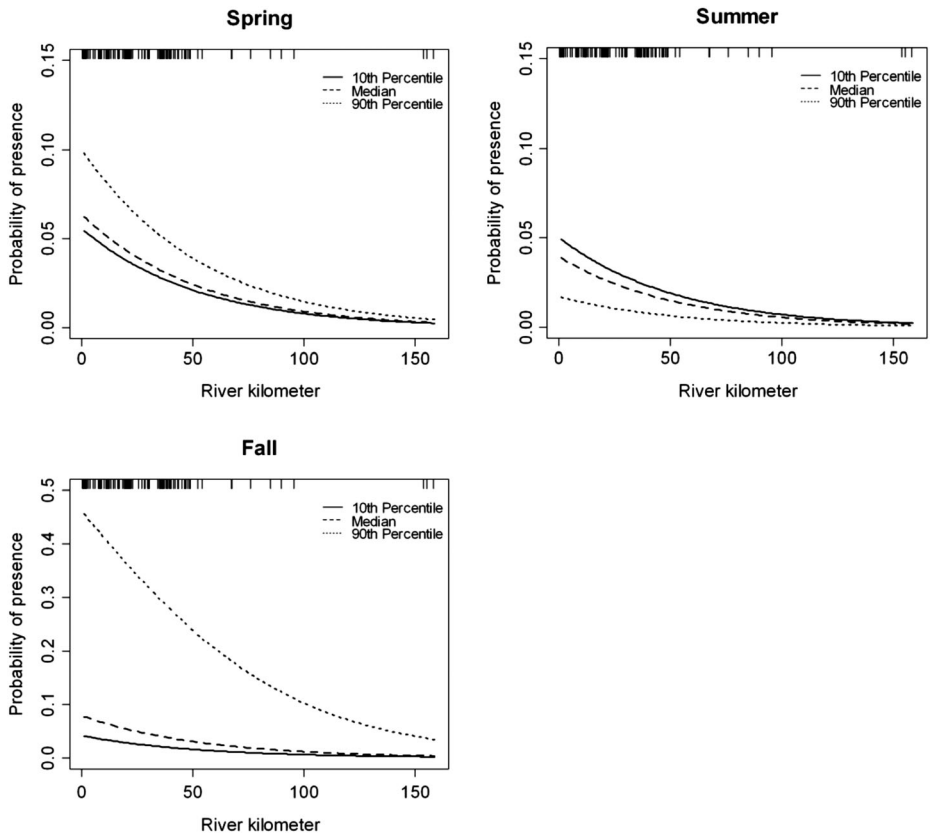

Figure 4. Predictive curves for the probability of pallid sturgeon occurrence throughout the lower Platte River (rkm 0–159) under the 10th ($108\,m^3\,s^{-1}$), median ($202\,m^3\,s^{-1}$), and 90th percentiles ($379\,m^3\,s^{-1}$) of the reported mean daily discharge for each sampling event (day). Tick marks at the top of each box represent actual locations of pallid sturgeon captures from 2009 to 2011

DISCUSSION

Pallid sturgeon were captured throughout the entire study reach of the lower Platte River (159 km) and were found throughout all three seasons annually. This was not expected because it was previously unknown if large riverine specialists, such as pallid sturgeon, use the entire lower Platte River outside of the spawning season. The Platte River tributary is clearly an important component to the metapopulation of pallid sturgeon as fish occupied habitat patches throughout the year, particularly during the fall sampling period. In addition, pallid sturgeon were collected in the upstream reaches (rkm 52–159) where they have not been documented. This wide distribution of pallid sturgeon occurrence provides additional evidence for the importance of the Platte River tributary outside of the lower portions of the river that are heavily influenced by the confluence with the Missouri River.

Factors that were responsible for the distribution of pallid sturgeon in the Platte River were best explained by factors associated with the flow regime. An interaction between river discharge during each of the three sampling seasons and the diel variation in flow was the best predictor for pallid sturgeon occurrence. Our model predicted the highest probability of local pallid sturgeon occurrence under high discharge regimes. For modelling purposes, we used the 90th percentile of the observed mean daily discharge values for all sampling occasions ($518\,m^3\,s^{-1}$) as the representative value for the high discharge classification. Discharge values near this range of flows are infrequent in the lower Platte River and usually are associated with high-precipitation events (Figure 6). Although it may not be feasible to allocate water for consistent flows of this magnitude at will, these results provide important information for future water management during years of above normal snowmelt or precipitation (e.g. environmental flow assessment).

There was a negative relation between high variability in daily flows and local pallid sturgeon occurrence during the spring and fall. Diel flow variation in the lower Platte River is a result of hydropeaking from a nearby power facility on the Loup River, a tributary to the Platte River (Figure 1). Water from the Loup River is diverted through a series of canals to the hydroelectric facility. After generating power, water is re-directed to the Platte River just downstream of the Loup River confluence. More water is used during periods of peak

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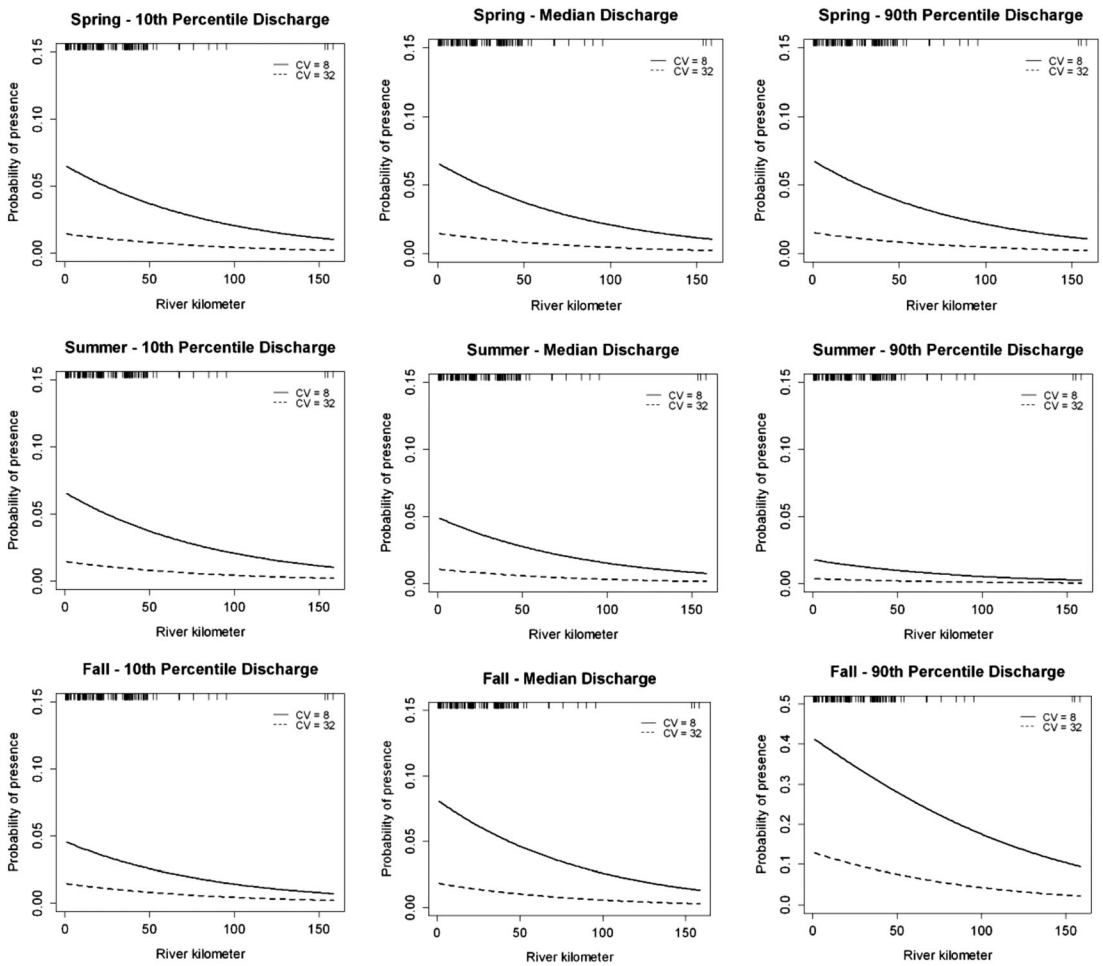

Figure 5. Predictive curves for the probability of pallid sturgeon occurrence throughout the lower Platte River (rkm 0–159) under the 10th (CV = 8) and 90th (CV = 32) percentile of the coefficient of diel variation for varying discharge regimes for each sampling season. Tick marks represent actual pallid sturgeon captures from 2009 to 2011

electricity usage, thereby creating large (>1 m) diel oscillations of water returns (Figure 7). These effects are exacerbated in the upper 107 km of the lower Platte River because very little base flow comes from the central Platte River because of water withdrawals for irrigation (Galat *et al*., 2005). These large oscillations in the hydrograph create drastic changes in river stage level, and many of the braided channels within the river are often stranded or completely desiccated during low-flow periods. Although the effects of hydropeaking are detectable in the hydrograph of the lower 52 km of the Platte River, substantial water inputs from the Elkhorn River buffer the magnitude of diel change, thereby negating stranding and desiccation during normal water years (Figure 7). This is likely the reason why the CV was not included in the top model from our results because CV is only a good predictor of pallid sturgeon presence where hydropeaking occurs.

The local probability of pallid sturgeon occurrence declined longitudinally from the mouth of the Platte River to the upstream most sampling site for all of our predictions. This precipitous decline beyond the confluence of the Elkhorn River (rkm 52) illustrates the effect that reductions in the quantity of water and diel fluctuations in flow can have on large-bodied riverine species. Many authors have shown that extremes in river flow and the patterns of flow variability directly affect the local community structure (Poff and Allan, 1995; Pusey *et al*., 2000; Biggs *et al*., 2005; Kennard *et al*., 2007; and others). Poff and Allan (1995) showed that streams with high flow variability had fish assemblages that were more characteristic of small streams and lentic systems that consisted of proportionately fewer medium to large-bodied river species. In streams with excessive variability, specialization of traits is unlikely to occur, and generalism is typically observed as the most successful strategy (Pusey *et al*., 2000; Mims and Olden, 2012).

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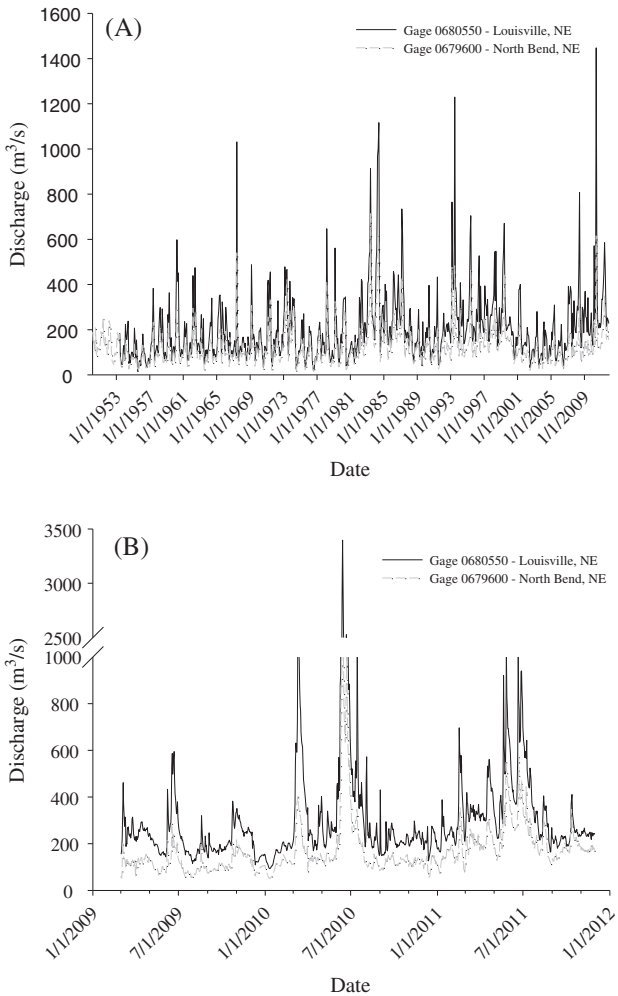

Figure 6. Mean monthly discharge (A) for all recorded years in the lower Platte River, Nebraska, at a gauging station above (Gage 0679600) and below (Gage 0680550) the Elkhorn River confluence. Also included is the mean daily discharge during the study period (2009–2011; B)

Therefore, reducing diel fluctuations in flow and water withdrawals for various purposes would likely increase the number of pallid sturgeon occurrences in areas above the Elkhorn River confluence.

Previous work has indicated that the spring is a high-use period in the lower Platte River for lotic species (Snook *et al*., 2002; Peters and Parham, 2008; Neely *et al*., 2009). River specialists such as pallid sturgeon and blue sucker *Cycleptus elongatus* initiate upstream movements coinciding with peaks in discharge and optimal temperature ranges. After spending a variable amount of time near their apex, most fishes move back downstream (Snook *et al*., 2002; Neely *et al*., 2009). Although large-bodied lotic species have been found in the lower Platte River outside of the spawning period, it is often assumed that the Platte River's ecological relevance is directly related to spawning (Peters and Parham, 2008). Our results show that the probability of pallid sturgeon occurrence was greatest during the fall sampling period, and occurrence was particularly high during periods of high discharge. Although the direct reasons for use are unknown, the lower Platte River may be providing habitats or resources that are not typically found in the Missouri River such as emergent sandbars and braided channels, available or abundant prey and refuge from high velocities.

Pallid sturgeon captures were low during the summer sampling period, regardless of environmental conditions. Contrary to expected results, our model predicted that the probability of local pallid sturgeon occurrence during the summer was highest under a low-flow regime. As previously described, summer flows are often low because of high water demand coupled with low precipitation. It is unknown how sampling gear efficiency is influenced by low flow. Summer flows also may congregate pallid sturgeon, and our site selection may have precluded us from collecting them. Future research to describe seasonal influences on catchability and summer use in the Platte River is needed.

Preserving or enhancing biodiversity of lotic species is challenging in that few free-flowing, large ($>350\,m^3\,s^{-1}$) river systems exist throughout much of the northern third of the world (Dynesius and Nilsson, 1994). Anthropogenic effects such as fragmentation by dams, water regulation from reservoir operations and water diversion and irrigation withdrawals have been linked to losses in biodiversity (Malmqvist and Rundle, 2002). Although the lower Platte River is subject to flow management from several water constituents, few physical alterations (i.e. dams and water control structures) have occurred resulting in a system that retains many of the historical characteristics such as shifting sandbars, braided channels and connectivity to the floodplain but is subject to water management issues. Therefore, the lower Platte River provides an opportunity to preserve and enhance ecological processes in a system that could be optimally managed to accommodate appropriate water management that emulates key elements of the natural flow regime.

Management of lotic systems will continue to be a difficult task as water managers are challenged to meet the needs of supplying suitable drinking water, irrigation, recreation and hydroelectricity production, while not degrading or disrupting freshwater ecosystems. Establishing environmental flows (Tharme, 2003; Arthington *et al*., 2006) has been used as an alternative to minimum flow thresholds by accounting for ecosystem processes while achieving sustainable water-resource management (Bobbi *et al*., 2013). Environmental flow assessments attempt to maintain freshwater biodiversity by identifying and conserving influential components of the natural flow regime (Poff *et al*., 1997) while accounting for water allocation for other water users (Lind *et al*., 2007). Future research is needed for developing

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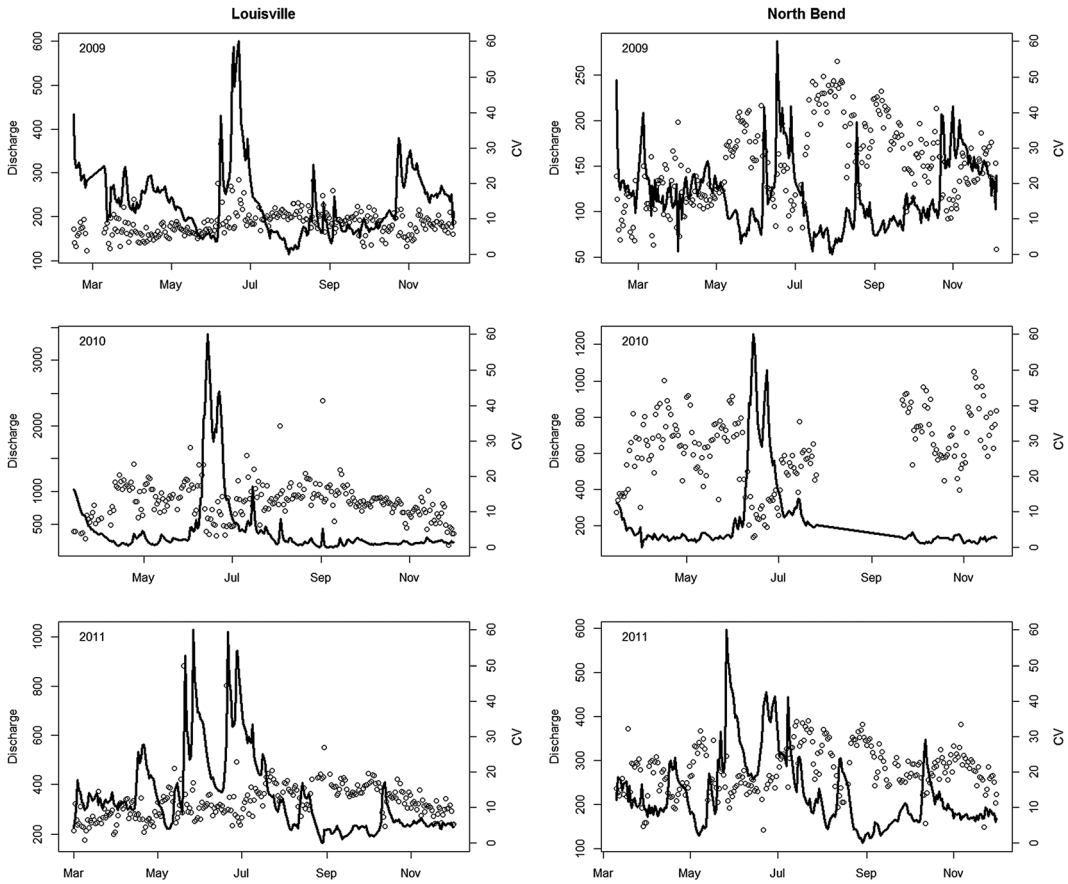

Figure 7. Mean daily discharge ($m^3 s^{-1}$) and diel coefficient of variation during the study period (2009–2011) in the lower Platte River, Nebraska, at a gauging station above (North Bend, NE; Gage 0679600) and below (Louisville, NE; Gage 0680550) the Elkhorn River confluence

a collaborative and adaptive approach for managing water to meet ecological and societal demands in lotic systems like the Platte River.

The role of tributary streams has gained recent attention for conservation of aquatic biodiversity (Kiffney *et al*., 2006; Sarkar *et al*., 2010; Pracheil *et al*., 2013). Tributaries typically are physically altered to a lesser degree and provide similar species assemblages in the lower portions of the river compared with main stems (Pracheil *et al*., 2009; Pracheil *et al*., 2013). Thus, tributaries may provide unique opportunities for restoration or conservation efforts aimed at preserving biodiversity of large riverine species (Pracheil *et al*., 2013). This may be particularly important for pallid sturgeon as the main-stem Missouri River has been permanently altered by dams and channelization, creating a fairly homogenous system with relatively uniform depths and velocities (Hesse and Sheets, 1993). Continued research in the Platte River and other large tributaries may provide insight into the importance of population connectivity at multiple scales for species persistence.

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