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Spatial analysis of pallid sturgeon *Scaphirhynchus albus* distribution in the Missouri River, South Dakota

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Summary

Movement and distribution of the endangered pallid sturgeon *Scaphirhynchus albus* has generally been documented using radio telemetry. However, because of the time and cost involved in tracking individual fish (i.e. small sample size), it is often difficult to evaluate spatial distribution of groups of fish over long time periods (> 3 years). Standardized sampling for pallid sturgeon, which relies on a variety of gear types, has been conducted on the Missouri River downstream of Fort Randall Dam annually since 2003. Using catch data from 2003 to 2006, the spatial distribution of juvenile pallid sturgeon was evaluated using spatial scan statistics. Presence ⁄ absence of pallid sturgeon was summarized from a variety of gear and distribution patterns were analyzed based on: (i) each gear per season, (ii) all gear pooled per season, (iii) each gear pooled across seasons, and (iv) pooled data from all gear and years combined. Three significant clusters of pallid sturgeon captures were identified when all gear and years were pooled. Distribution patterns identified using data from summer trammel nets agreed well with the overall pooled dataset and could be used to identify areas with a high probability of pallid sturgeon presence. This methodology can be used to identify areas where pallid sturgeon are likely to occur, thus improving sampling efficiency for monitoring vital statistics for this endangered species. Moreover, this approach could be applied to other reaches of the Missouri River using existing data from the Pallid Sturgeon Monitoring and Assessment Program. Once identified, these areas could then be evaluated to better understand the habitat requirements of pallid sturgeon.

Introduction

The pallid sturgeon *Scaphirhynchus albus* is a federally endangered species native to the Missouri and lower Mississippi rivers (Dryer and Sandvol, 1993). Natural reproduction for this species is limited in the Missouri River and has not been able to sustain the population. As a result, pallid sturgeon are now spawned in hatcheries and juvenile fish have been stocked into many reaches of the Missouri River since 1994 as part of efforts to recover the species (Krentz et al., 2005).

Monitoring of stocked juvenile pallid sturgeon represents an essential component of the recovery effort using an adaptive management framework (Prato, 2003). Standardized sampling, which relies on a variety of gear types, has been conducted since 2003 in the Missouri River downstream of Fort Randall Dam, herein called the Fort Randall reach (Shuman et al., 2007). Although information collected from the monitoring and assessment program has been useful for evaluating growth and abundance of pallid sturgeon, these data have not been used to quantify their spatial distribution in the Missouri River.

Movement and distribution of pallid sturgeon are generally documented using radio telemetry (Hurley et al., 2004; Gerrity, 2005; Jordan et al., 2006). However, because of the time and cost involved in tracking individual fish (i.e. small sample size), it is often difficult to evaluate spatial distribution of groups of fish over long time periods (> 3 years). Moreover, these methods do not account for other individuals (e.g. non-tagged fish) that may be in close proximity to the study fish (Kieffer and Kynard, 1993; Ng et al., 2007). Understanding spatial trends in the distribution patterns of pallid sturgeon could help focus recovery efforts for the species by identifying important habitat characteristics.

One approach to evaluating the spatial distribution of fishes based on multiple years of capture data is with spatial scan statistics. To our knowledge, this approach has received little, if any, attention in freshwater fisheries applications, but is frequently used in epidemiology (Dreesman and Scharlach, 2004; Kulldorff et al., 2005) and crime studies (Jeffries, 1998) to evaluate the spatial distribution of these phenomena. Results from such analyses can then be used to examine whether spatial attributes of certain areas explains clustering of the phenomenon (Cousens et al., 2001; Mostashari et al., 2003; Brooker et al., 2004).

In this study, we used spatial scan analysis to explore the distribution (i.e. clustering) of pallid sturgeon captures in the Fort Randall reach of the Missouri River. We used multiple years of capture data (2003–2006) from four different gear types (two active and two passive) to evaluate spatial distribution patterns of pallid sturgeon. We discuss the usefulness of this approach for evaluating standardized monitoring data and the implications for using specific combinations of gear and seasons for documenting pallid sturgeon distribution.

Study area

In 2003, the United States Army Corps of Engineers coordinated a multiple state and federal agency standardized sampling effort to assess the success of pallid sturgeon stocking in the Missouri River (Drobish, 2006). Capture data for pallid sturgeon were obtained from the 103-km segment of the Missouri River known as the Fort Randall reach located on the border of South Dakota and Nebraska (Fig. 1). The reach is unique in that it can be divided into riverine (~ 55 rkm), braided depositional (~ 24 rkm), and reservoir (~ 24 rkm) habitat areas. The Fort Randall reach is an impounded portion of the Missouri River that is bounded upstream at Fort Randall Dam, near Pickstown, South Dakota (rkm 1416) and extends downstream to Gavin's Point Dam, near Yankton, South Dakota (rkm 1305). The depositional area is characterized by a large braided delta formed by sediment inputs from the Niobrara River, the major tributary that flows into this particular reach of river at rkm 1351. Water discharge from Fort Randall Dam is regulated by the United States Army Corps of Engineers (USACOE) for water control and hydroelectric power production.

The Fort Randall reach has a total of 27 river bends, 17 in the riverine section and 10 in the depositional delta. A river bend is comprised of an upstream channel crossover (area where the thalweg flows from one bank to the opposite bank), the inside bend (depositional area adjacent to the thalweg), and a corresponding outside bend (high velocity erosional area adjacent to the thalweg) of the main channel.

Materials and methods

The pallid sturgeon monitoring and assessment protocol established standardized sampling methods and gear specifications (Drobish, 2006) for both passive gear (stationary gillnets and setlines) and active gear (otter trawls and trammel nets). A minimum of 10 river bends were randomly chosen for sampling each year from 2003 through 2006, with the exception of two bends, one upstream of and the other at the confluence of the Niobrara River and Missouri River during 2003 and 2004. All gear deployments were geospatially referenced with latitude and longitude recorded using either a WAAS enabled Garmin GPSMAP 168 echo sounder or GPSMAP 76 GPS unit (precision of 3–10 m).

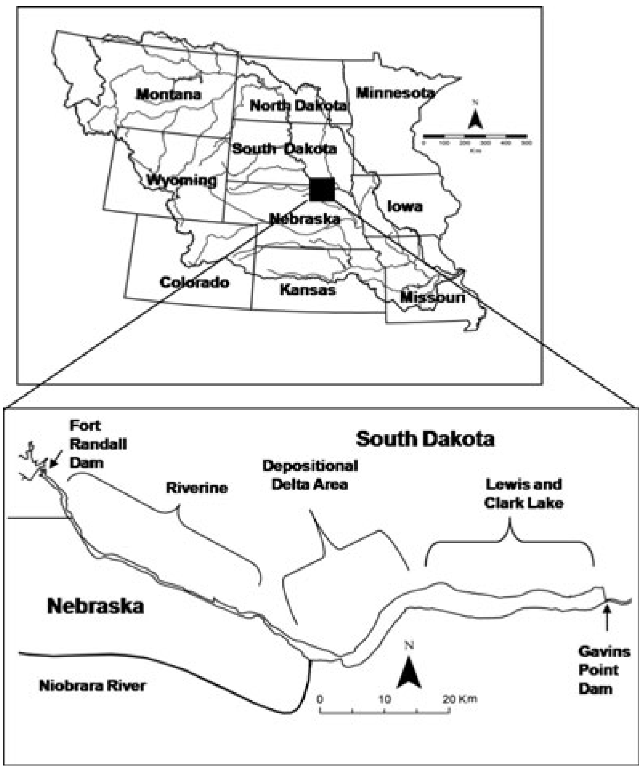

Fig. 1. Missouri River watershed (top panel) and study area (bottom panel) between Fort Randall and Gavin's Point dams, South Dakota and Nebraska USA. Sample areas in 2003–2006 for juvenile pallid sturgeon *Scaphirhynchus albus* were located in the riverine and depositional delta areas of the reach.

Gillnets were deployed as a passive gear when water temperatures were less than 12.8°C to minimize the chance of pallid sturgeon mortality (Drobish, 2006). Each gillnet was composed of multifilament netting in bar mesh sizes of 2.5, 3.8, 5.1, 7.6, and 10.2 cm in five 8 m long panels for a maximum length of 38 m. These nets were anchored parallel to the current and fished overnight in the spring (March–May) and autumn (October–November). On average, 160 gillnets were deployed per year from 2003 through 2006 in the Fort Randall reach (Shuman et al., 2005, 2006, 2007).

Setlines were constructed of 2 m long, 27.2 kg-test nylon braided twine and rigged with 10 ⁄ 0 and 12 ⁄ 0 circle hooks baited with earthworms *Lumbriscus terrrestris* or leeches *Theromyzon* spp. (Wanner et al., 2007). The setlines were deployed overnight and anchored by a 1.4 kg folding grapnel anchor in spring, summer (June–September), and autumn. On average, over 500 setlines were deployed annually from 2003 through 2006.

Otter trawls were constructed of outer polyethylene netting consisting of 3.8 cm stretch outer chafing mesh and an inner mesh size of 0.63 mm bar. The trawl width was 4.8 m wide and 0.91 m high and was pulled along the bottom of the river from an upstream to downstream direction at a speed slightly faster than the current for a targeted distance of 300 m and a minimum of 75 m. Distance of each trawl was measured with a GPS. Otter trawls were deployed in spring, summer, and autumn starting in 2005, and on average 180 trawls were conducted annually.

Trammel nets were constructed of multifilament nylon netting with a 2.4-m deep inner wall and a 1.8-m deep outer wall that was 38.1 m long with the inner bar mesh of 2.5 cm and an outer bar mesh of 20.3 cm. Trammel nets were drifted along the river bottom from an upstream to downstream direction for a maximum distance of 300 m and minimum of 75 m. Distance of each drift was recorded using GPS. Trammel nets were deployed in the spring, summer, and autumn seasons with an average of 296 trawls deployed annually from 2003 to 2006.

All capture and non-capture locations for pallid sturgeon were entered into the spatial scan statistical program SaTScan™ version 7.0.3 (Kulldorff, 2006) to identify 'clusters' of capture and non-capture areas. This procedure used variable-sized circular neighborhoods to test for evidence of clustering. For this purpose, we set the maximum size radius at 1.6 km based on the measured mean daily movement rate for juvenile pallid sturgeon in the Missouri River downstream of Fort Randall Dam (Jordan et al., 2006).

A Bernoulli likelihood ratio function (Kulldorff, 1997) was calculated for each neighborhood to determine the strength of the cluster as a likelihood function (L) where;

$$L = \left(\frac{c}{n}\right)^{c} \left(\frac{n-c}{n}\right)^{n-c} \left(\frac{C-c}{N-n}\right)^{C-c} \left(\frac{(N-n)-(C-c)}{N-n}\right)^{(N-n)-(C-c)},$$

C is the total number of pallid sturgeon capture locations, c is the number of pallid sturgeon captures within the circle (radius ≤ 1.6 km), N is the sum of all captures and non-captures within the study area, and n is the sum of pallid sturgeon captures and non-captures within the test circle. This likelihood ratio test assumes that the overall effort (sum of captures and non-captures) is not constant across the study area (Kulldorff and Nagarwalla, 1995). Clusters with a high calculated likelihood function are less likely to have occurred by chance, and can be tested statistically using Monte Carlo simulations. A P-value is calculated by ranking the likelihood of the observed dataset compared to the distribution of the likelihoods resulting from the Monte Carlo simulations. A random selection of 10 000 permutations of the data points for captures and non-captures were used to identify significant non-overlapping clusters ($P < 0.05$). Distribution of pallid sturgeon presence or absence was analyzed for (i) each gear in each season, (ii) pooled gear in each season, (iii) each gear separately pooled for all seasons, and (iv) the overall pooled dataset. Spatial scan analysis was used to identify areas of both pallid sturgeon occurrence (clustering) and absence based on presence and absence data. The analysis was performed for three seasons: spring (March through May), summer (June through September), and autumn (October through November). A total of 19 combinations of season and gear deployments were analyzed to determine if consistent clusters were identified across gear types and time periods. The cluster distributions of individual gear types in separate seasons were compared to the clustering patterns from the pooled dataset.

Spatial scan analysis is binomial and not continuous, because it is based on presence (capture) and absence (non-capture) data. Although effort for individual gear types was standardized, the number of fish captured within an individual deployment is not considered in the model. Hence, multiple pallid sturgeon captured in a single gear deployment are counted singly as 'present' and the location is not weighted to account for multiple fish. In order to weight areas with multiple captures more than areas that had single captures, we adjusted the recorded capture locations by 1 m from the original gear deployment location. Although this small adjustment in fish location had little effect on the actual location of captured fish, it provided more importance to areas where multiple fish were captured.

Results

A total 120 pallid sturgeon were captured in 3417 gear deployments from 2003 through 2006 (Table 1). Pallid sturgeon fork length varied from 321 to 1430 mm with a mean fork length of 531 mm. Trammel nets caught the most pallid sturgeon (n = 63) in the 4 year sample period. Otter trawls caught the fewest number of pallid sturgeon (n = 11), but were only used for 2 years (2005–2006). Setlines were deployed the most, but caught the fewest fish (n = 18). Pooled gear deployments and pallid sturgeon captures were not evenly distributed by river kilometer (Fig. 2). More than one pallid sturgeon was captured in 13 trammel net deployments, and in four gillnet deployments from 2003 to 2006. However, we never collected more than one pallid sturgeon per otter trawl or setline (Table 2).

Spatial scan analysis identified nine significant clusters of pallid sturgeon captures in the Fort Randall reach (Table 1). Cluster locations were identified in areas where total pallid sturgeon captures were high (> 6 fish) and effort was moderate (3–10 deployments) (Fig. 2). The surface area of regions (i.e. clusters) characterized by pallid sturgeon captures ranged from 0.002 to 3.60 km^2. The analysis that included all gear and seasons identified the most clusters (n = 3) of pallid sturgeon captures, two of which were located in the same river kilometer, but in different channels of the depositional delta area of the river reach. No single subset of data found clusters of pallid sturgeon in areas where other subsets of the data did not also identify clusters. Significant clustering of pallid sturgeon was found around rkm 1357 near the Ponca Creek confluence for each of the five subsets of the data where clustering was observed, and three of the five data subsets identified pallid sturgeon clustering around rkm 1336 in the depositional delta area (Fig. 2). Evidence that pallid sturgeon were significantly clustered in certain areas was obtained from autumn setlines, summer trammel nets, all season trammel nets, all gear in the summer, and all gear in all seasons. Data subsets that did not identify any clusters of pallid sturgeon

Table 1
Summary of pallid sturgeon *Scaphirhynchus albus* captures and non-captures by gear type for summer (June–September), autumn (October–November), spring (March–May) and all seasons combined in the Missouri River downstream of Fort Randall Dam, South Dakota and Nebraska, USA, 2003–2006

				Number of clusters P < 0.05		Total surface area of clusters (km^2)	
Season	Gear type	Total non-captures	Pallid sturgeon captures	Pallid sturgeon	Non-capture	Pallid sturgeon	Non-capture
All	All	3297	120	3	1	0.26	0.93
	Gill nets	597	28	0	0	0	0
	Trammel nets	1016	63	2	0	0.05	0
	Setlines	1534	18	0	0	0	0
	Otter trawls	150	11	0	0	0	0
Summer	All	1386	58	1	2	0.002	15.95
	Trammel nets	557	41	2	1	3.60	7.94
	Setlines	809	8	0	0	0	0
	Otter trawls	7	7	0	0	0	0
Spring	All	1294	27	0	0	0	0
	Gill nets	349	9	0	0	0	0
	Trammel nets	351	13	0	0	0	0
	Setlines	519	4	0	0	0	0
	Otter trawls	75	1	0	0	0	0
Autumn	All	617	35	0	0	0	0
	Gill nets	235	17	0	0	0	0
	Trammel nets	108	9	0	0	0	0
	Setlines	206	6	1	0	3.06	0
	Otter trawls	68	3	0	0	0	0

The number of significant clusters ($P < 0.05$) of capture and non-capture areas was determined using spatial scan statistics.

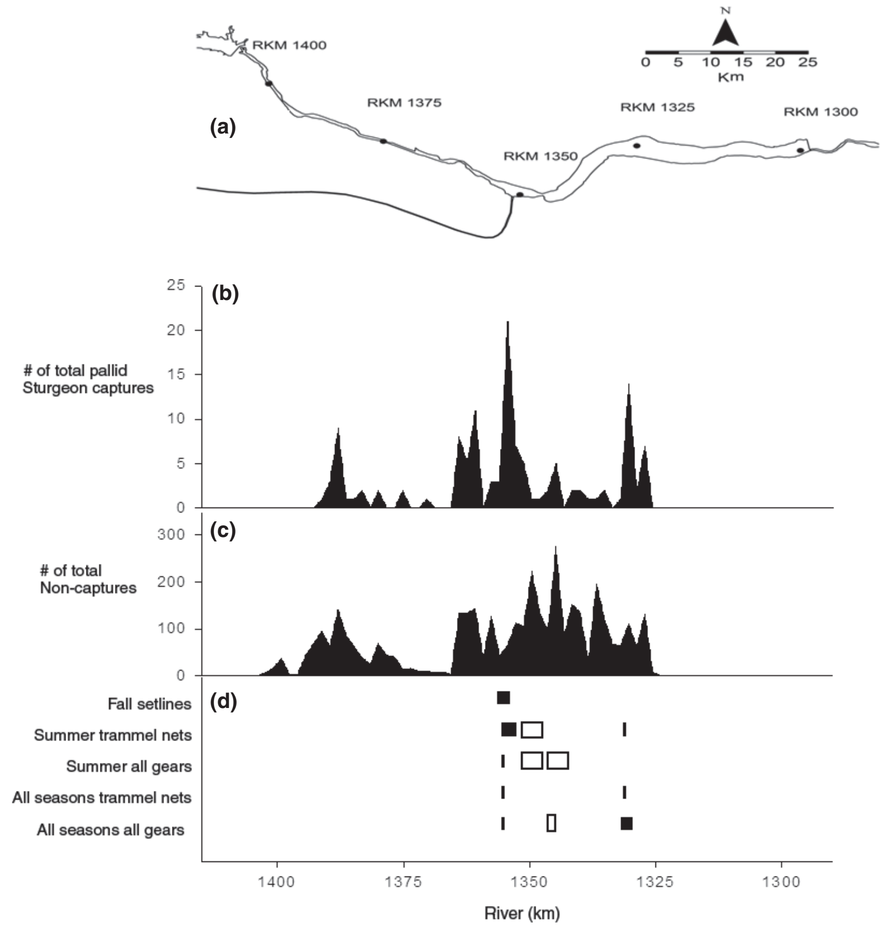

Fig. 2. (a) Map of Fort Randall reach of the Missouri River showing river kilometers (rkm), South Dakota and Nebraska USA. (b) Plot of total pallid sturgeon *Scaphirhynchus albus* captures and (c) total non-captures by rkm, 2003–2006, used in spatial scan analysis. (d) River segments (rkm) where significant clustering ($P < 0.05$) occurred for pallid sturgeon captures (blackened bars) or non-captures (open bars) for each of five data sets that had significant clusters. Width of bars indicate approximate cluster size

Table 2
Summary of multiple pallid sturgeon *Scaphirhynchus albus* captures by gear type during summer (June–September), autumn (October–November), or spring (March–May) 2003–2006 sampling in the Missouri River downstream of Fort Randall Dam, South Dakota and Nebraska, USA

		Number of gear deployments that captured	
Season	Gear type	Two pallid sturgeon	Three pallid sturgeon
Summer	Trammel nets	8	1
	Otter trawls	0	0
	Setlines	0	0
Spring	Trammel nets	1	1
	Otter trawls	0	0
	Setlines	0	0
	Gill nets	1	0
Autumn	Trammel nets	1	1
	Otter trawls	0	0
	Setlines	0	0
	Gill nets	2	1

occurrence or absence were all otter trawls regardless of season, all gillnets regardless of season, all gear in the spring and autumn, and all set lines in the summer, spring and combined seasons.

Four areas of pallid sturgeon absence (i.e. non-captures) were found. Non-capture clusters were identified in three subsets including summer trammel nets, all gear in all seasons, and all gear in the summer months. Clusters of non-captures were found around rkm 1348 and 1343, downstream of the confluence of the Niobrara and Missouri rivers, for more than one data subset (Fig. 2). Cluster locations for non-captures were identified in areas where pallid sturgeon were generally not captured, despite effort being moderate (Fig. 2). Analyses that found significant evidence of pallid sturgeon absence were summer trammel nets, all gear in the summer, and all gear in all seasons. Total surface area of regions characterized by non-captures ranged from 0.93 to 15.95 km^2 (Table 1).

Discussion

One advantage of spatial scan analysis is that the locations of clusters are not limited by sample zone boundaries. Boundaries established in the standardized sampling protocol for pallid sturgeon can be hard to determine, making it difficult to define exactly where a bend ends and another begins. Spatial scan analysis is not affected by boundary locations and provides a more parsimonious way to determine spatial patterns of occurrence (Coulston and Riitters, 2003). In this study, the point sample locations were analyzed for clustering and were not restricted by bend boundaries. This approach allowed for identification of capture areas that may have overlapped bend boundaries. These capture areas could have been composed of multiple captures of pallid sturgeon over a 4-year time frame that may have been sampled in two different bends but at the same latitude and longitude based on the dynamic nature of the river channel.

Another benefit of the spatial scan approach was that pallid sturgeon clusters could be identified using only trammel nets in the summer. The spatial scan analysis of summer trammel nets identified clusters of pallid sturgeon occurrence in the same areas as those identified by the pooled dataset of all gear and seasons. A seasonal assessment of pallid sturgeon sampling gear showed that season dictated the effectiveness of sample gear types (Wanner et al., 2007). Within-gear type comparisons indicated that trammel nets were most effective in the summer, gillnets were most effective in the autumn and, setlines were most effective in the spring to capture pallid sturgeon based on catch per unit effort (Wanner et al., 2007). This evidence, and high sample size in this study suggests that sampling with summer trammel nets can be used to reliably identify distribution patterns of pallid sturgeon. Gillnets and setlines may not have been deployed at a high enough rate in order to detect clusters during the most effective time of year for the gear type. Considerable time and effort could be saved when trying to assess spatial distribution patterns of pallid sturgeon by eliminating gear that were found to be ineffective at identifying pallid sturgeon clustering.

One assumption of SaTscan is that the total number of sample locations must be high enough to detect significant clusters of pallid sturgeon capture and non-capture and the size of the circular window must be large enough to enclose a number of locations (Kulldorff, 1997). Although the pooled dataset from 4 years of sampling was used to maximize the spatial coverage of gear deployments and captures, some areas of the Fort Randall reach were sampled more intensively than others. There were numerous sampling locations where pallid sturgeon were not captured from 2003 to 2006. However, only two areas were identified that contained significant clustering of non-capture events (near rkm 1343 and 1348).

There are four obvious peaks of pallid sturgeon occurrence when plotted as captures by river kilometer (Fig. 2). However, only two of these peaks, near rkm 1336 and rkm 1357, were statistically significant. Two other areas, rkm 1362 and rkm 1379, had high pallid sturgeon occurrence but significant clusters were not identified in the analysis. Because of the spatial variability in sampling effort, we may have lacked statistical power to detect some true clusters in portions of the river where sampling effort was low.

Another assumption in this model is that the data points entered into the spatial scan statistical model are representative of the entire population. A study of West Nile Virus occurrence, indicated by the presence of dead bird reports (Mostashari et al., 2003), found that several underlying factors besides disease may influence the observed clusters of the virus such as public sighting and willingness to report sightings. In this study, an important consideration is that there are no false absences in the data set. Each non-capture location should be an actual non-occurrence, and not an area where a gear deployment was unsuccessful at capturing a pallid sturgeon. Although we used multiple gear to maximize the probability of capturing pallid sturgeon, no sampling gear is 100% effective (Hayes et al., 1996); thus, we viewed the number of clusters identified by this approach as conservative.

An important finding from the spatial scan analysis was that pallid sturgeon appeared to be consistently captured around rkm 1357, particular during summer and to a lesser extent the autumn sampling seasons. Interestingly, only setline gear detected any clustering from autumn sampling efforts, suggesting that this gear may be efficient for capturing pallid sturgeon in the autumn. During autumn, decreased capture efficiency and / or reduced gear deployments (Wanner et al., 2007) may have reduced our ability to detect significant clustering of pallid sturgeon captures.

Spatial scan analysis shows promise for assessing distribution patterns of pallid sturgeon. Once identified, these areas can provide important information about habitat use that could be extended to other segments of the Missouri River. However, there are limitations that need to be considered when applying this technique. In the present application, a circular window proved effective for identifying clusters along a single, relatively linear stretch of a large river. However, circles may not be an effective metric of spatial proximity in more complex, dendritic channel networks. Future development of the spatial scan statistic for monitoring pallid sturgeon distribution should consider using linear segments of the riparian network as scanning windows (i.e. instead of circles), and accounting for variability in sampling effort (i.e. uniform distribution of sampling effort).

The use of SaTscan analysis to identify distribution patterns of pallid sturgeon could be an effective alternative to telemetry methods in identifying important habitats for juvenile pallid sturgeon. Movement and distribution of pallid sturgeon are generally documented using radio telemetry, but because of the time and cost involved in tracking individual fish (i.e. small sample size), it is often difficult to evaluate the spatial distribution of groups of fish. The approach used here incorporates spatial and temporal information from multiple captures to identify significant 'clusters' of pallid sturgeon captures. Identification of these areas is an essential step in aiding the recovery of the pallid sturgeon because it provides a basis for more intensive study of the habitat characterizing these regions.

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