

## ABIOTIC FACTORS AFFECTING SUMMER DISTRIBUTION AND MOVEMENT OF MALE PADDLEFISH, *POLYODON SPATHULA*, IN A PRAIRIE RESERVOIR

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**ABSTRACT**—Six male paddlefish, *Polyodon spathula*, were implanted with ultrasonic temperature-sensing transmitters and tracked during June through August 1997 to quantify effects of physicochemical conditions on their distribution and movement in Keystone Reservoir, Oklahoma. Paddlefish moved about twice as much during night than day. Movement rate of paddlefish was related to reservoir water level, inflow, and discharge from the reservoir at night; however, none of these variables was significant during the day. Location in the reservoir (distance from the dam) was negatively related to water level and positively related to inflow during day and night periods. Location in the reservoir was negatively related to discharge during the day. Paddlefish avoided the highest available water temperatures, but did not always avoid low dissolved oxygen concentrations. Paddlefish avoided the Cimarron River arm of the reservoir in summer, possibly because of high salinity. Our study demonstrates that distribution of paddlefish during summer and movement in Keystone Reservoir was influenced by physicochemical and hydrologic conditions in the system. However, biotic factors (e.g., food availability) not measured in this study may have been influenced by abiotic conditions in the reservoir.

**RESUMEN**—Se implantaron transmisores ultrasónicos sensores de temperatura a seis machos de *Polyodon spathula* y se les siguió de junio a agosto de 1997 para cuantificar los efectos de las condiciones fisicoquímicas en su distribución y movilidad en Keystone Reservoir, Oklahoma. *Polyodon spathula* se trasladó dos veces más durante la noche que durante el día. La tasa de movimiento de *P. spathula* estuvo relacionada con el nivel del agua de la reserva, entrada de agua, y descarga de la reserva durante la noche; sin embargo, ninguna de estas variables fue significativa durante el día. La localización en la reserva del *P. spathula* (distancia de la presa) estuvo relacionada negativamente al nivel del agua y positivamente relacionada a la entrada de agua durante los periodos del día y la noche. Su localización en la reserva estuvo negativamente relacionada a la descarga durante la noche. *Polyodon spathula* evadió las más altas temperaturas del agua disponibles, pero no siempre evadió bajas concentraciones de oxígeno disuelto. *Polyodon spathula* evadió la rama de la reserva del Cimarron River en el verano, posiblemente por la alta salinidad. Nuestro estudio demuestra que la distribución durante el verano de *P. spathula* y su movimiento en Keystone Reservoir estuvo influenciado por condiciones fisicoquímicas e hidrológicas en el sistema. Sin embargo, factores bióticos (e.g., disponibilidad de comida) no medidos en este estudio pudieron también haber sido influidos por las condiciones abióticas en la reserva.

The paddlefish, *Polyodon spathula*, is native to large free-flowing rivers of the central United States where they thrive in backwaters, oxbows, and deepwater channel habitats. In spring, paddlefish in large rivers make extensive spawning migrations (Russell, 1986), moving among pools during high water and associating with tailwater (when dams are present) and turbulent main-channel border habitats

(Southall and Hubert, 1984; Moen et al., 1992). Over the past several decades substantial populations of paddlefish have developed in reservoirs of large rivers (Russell, 1986). Paddlefish presumably exhibit springtime movement and habitat use patterns in reservoir systems comparable to those in large river systems (Combs, 1982; Paukert, 1998); however, we know little about summer distribution

and movement patterns of paddlefish in reservoirs.

Habitat preferences of paddlefish during the spring spawning period are generally understood (Hubert et al., 1984; Southall and Hubert, 1984; Crance, 1987; Brandtly, 1987; Moen et al., 1992); however, summer habitat requirements are less well known, particularly in reservoirs. Because of the diverse and unpredictable physicochemical habitats that paddlefish occupy, due in part to anthropogenic alterations (impoundment, regulated flows) of riverine environments, there is a need to determine habitat preferences of paddlefish under a variety of environmental conditions (Moen et al., 1992) and during seasons other than spring. To our knowledge, no one has examined the physicochemical and hydrologic factors influencing summer distribution and movement of paddlefish in reservoir environments.

Keystone Reservoir is a prairie impoundment in northcentral Oklahoma with an established paddlefish population and diverse physicochemical and hydrologic conditions. For example, the Cimarron River arm of Keystone Reservoir has salinities about four times higher than those in the Arkansas River arm, which creates a salt-heavy underlayment of water in the reservoir during summer (Eley, 1967). Little is known about salinity preferences of paddlefish. W. H. Neill et al. (in litt.) determined that paddlefish avoid high salinity levels in the laboratory; however, no concurrent field studies were conducted. In contrast, paddlefish tagged in Texas appeared to move through salt water and have been recaptured in Louisiana (B. Reed, Louisiana Department of Wildlife and Fisheries, pers. comm.). Our objective was to determine physicochemical and hydrologic factors affecting summer distribution and movement of paddlefish in Keystone Reservoir.

**METHODS—Study Site**—Keystone Reservoir is a 10,600-ha impoundment of the Arkansas and Cimarron rivers in northcentral Oklahoma with a maximum depth of 23.3 m and a mean depth of 7.7 m. In spring and summer, large water-level fluctuations (>4 m) are common due to unpredictable inflows into the reservoir and outflows for flood control and power generation. Surface water temperatures can be extreme, reaching 34°C. Keystone Reservoir becomes thermally and chemically stratified in summer, with higher salinity concentrations in the hy-

polimnion. The Cimarron River drains highly mineralized subsurface deposits of natural salts and gypsum in western Oklahoma producing high conductivity levels in the Cimarron River arm (Eley, 1970). The Arkansas River drains the southern plains of Colorado and Kansas and has high concentration of calcium and magnesium sulfate (Eley, 1970). The Salt Fork of the Arkansas River, a major tributary, is heavily influenced by naturally occurring salt flats in northwestern Oklahoma.

**Field Collections**—We captured paddlefish in monofilament gill nets (Paukert and Fisher, 1999) fished overnight on 1 and 6 March 1997. Fish were implanted with crystal-controlled, temperature-sensing ultrasonic transmitters (Sonotronics, Tucson, Arizona) with a 24-month battery life and a range of 3,000 m. Ultrasonic transmitters were chosen over radio transmitters (Fisher and Wilkerson, 1997) because of the high conductivity levels (up to 5,000  $\mu\text{S}/\text{cm}$ ) in the reservoir. Each transmitter had a unique aural code set at a frequency of either 74.0 kHz or 76.0 kHz allowing identification of individual fish. Captured fish were placed in a 538-1 holding pen and weighed, measured (eye-to-fork length [EFL]; Ruelle and Hudson, 1977), and jaw-tagged with an individually numbered monel tag. Transmitter implantation procedures were similar to those described by Hart and Summerfelt (1975) with minor modifications (Paukert, 1998). We implanted transmitters in six male paddlefish (range, 843-1,000 mm EFL, 11.5-19.0 kg) on 2 and 7 March 1997. No females were collected, presumably because these fish and the larger males had moved up the rivers to spawn just prior to our sampling efforts (Paukert, 1998). Surgery time ranged from 8 to 12 min. Fish were then held in the water at boat side until they were able to swim off under their own power. Fish were monitored for about 30 min afterwards to verify movement away from the boat.

We searched the lower Keystone Reservoir system for transmitter-tagged fish by boat during June to August 1997 with a digital receiver (Sonotronics model USR 5W) and directional hydrophone (Sonotronics model DH-2). Periodic monitoring of fish from March to May 1997 was conducted to determine spring spawning migrations (Paukert, 1998). Paddlefish were tracked for this study at 3-h intervals from 0700 to 1900 h on 17 to 19 June, 30 June to 2 July, and 28 to 30 July, and were tracked from 2100 to 0600 h on 6 to 8 July, 3 to 5 August, and 10 to 12 August. Fish were located no more than once during each 3-h period. Keystone Reservoir was systematically searched for transmitter-tagged paddlefish beginning at the area where the fish were last located (usually the Arkansas River arm); most of the fish remained in the same general area (within about 5 km of each other). When all fish were not located within the 3-h period, we attempted to search the

TABLE 1—Categories of water temperature and dissolved oxygen for each of the three sampling periods used in water chemistry analysis of Keystone Reservoir. Nighttime sampling periods of 6–8 July, 3–5 August, and 10–12 August 1997 were removed from analysis because of uniformity of temperatures or low sample size.

Date	Temperature (°C)				Dissolved oxygen (mg/l)			
	Low	Moderate	High	Range	Low	Moderate	High	Range
17–19 June 1997	<24	24–25	>25	22–26	<4	4–6	>6	0–8
30 June–2 July 1997	<27	27	>27	26–28	<5	5	>5	2–6
28–30 July 1997	<27	27–29	>29	26–32	<5	5–7	>7	0–12

entire reservoir. A global positioning system receiver (Geoexplorer II, Trimble Navigation Inc., Sunnyvale, California) was used to determine geographic coordinates of the transmitter-tagged fish when we could hear the signal equally in all directions.

At each fish location, water temperature, dissolved oxygen (DO), and conductivity were measured at 1-m depth intervals with a multi-parameter water quality meter (model H20, Hydrolab Inc., Austin, Texas). When more than one fish was located in close proximity to another (<500 m), only one profile was taken. To characterize water chemistry conditions throughout the reservoir, we classified Keystone Reservoir into six areas, based on a previous temperature study of the reservoir (A.V. Zale et al., in litt.), and recorded water chemistry profiles in each of the six areas during each 3-day period when paddlefish were monitored. Hydrologic data (reservoir water level, discharge from the dam, inflow into the reservoir) were collected from the United States Army Corps of Engineers Keystone Dam facility.

Point locations of fish were overlaid onto a map of the reservoir using geographic information systems software (ARC/INFO, Environmental Systems Research Institute, Inc. Redlands, California). Movement rates were then calculated by measuring the shortest over-water distance between two points. To determine fish position within the reservoir, 500-m sections of the reservoir were measured at intervals along the centerline of the reservoir starting at the dam. Locations were then overlaid onto the 500-m grid to determine how far the fish was from the dam.

Because water chemistry differed among reservoir areas during the study, areas could not be combined to obtain overall available water chemistry conditions in the reservoir. Water chemistry conditions changed between each 3-day sampling period, but remained relatively constant within each period. Thus, we combined areas in which fish were located by arbitrarily categorizing water temperature and DO data as high, moderate, or low (Table 1). Areas of the reservoir were combined to include at least one vertical meter of the same temperature or DO category. For example, when we categorized moderate temperatures as 24–25°C, all areas that fish

were located in during a 3-day period had at least one vertical meter with a temperature from 24–25°C. To select or avoid a certain water chemistry category, a fish would need to move vertically within an area. To remain in the same category, a fish could move laterally among areas.

To address the problem of pseudo-replication in movements, White and Garrott (1990) suggested that observations are independent if an animal has enough time to move from one end of its home range to another. The summer home range for a paddlefish was determined to be the entire area of Keystone Reservoir it occurred in throughout the study period. The overall linear distance of the home range (20.8 km) was calculated and divided by the maximum movement rate of the fish (4.1 km/h). Thus, the minimum time it would take for a fish to cover the entire home range was determined to be 5.1 h. Using this criterion, all repeated observations  $\leq 5.1$  h for the distance from the dam and water chemistry measurements were excluded.

*Statistical Analyses*—A Wilcoxon rank sum test was used to compare movement rates (m/h) for daytime and nighttime periods and for upstream and downstream movement rates. Spearman rank correlations were used to determine relationships between movement rates and distance from the dam to inflow, discharge, and water level. Correlations were used in lieu of regressions because we measured only abiotic variables and did not want to infer causation based on these factors alone. Movement was categorized as either upstream, downstream, or static (movement of less than a 45 degree angle from the main channel axis). Water temperatures where the fish was located were recorded from the implanted temperature-sensing transmitters. Depth, conductivity, and DO levels where the fish was located were determined by comparing the temperature from the transmitter with the corresponding water chemistry profile values from that area. Chi-square analysis was used to determine if fish selected or avoided areas of the reservoir based on temperature or DO conditions. Bonferroni multiple comparison procedures were used to determine differences among water chemistry categories (Neu et al., 1974). All analyses

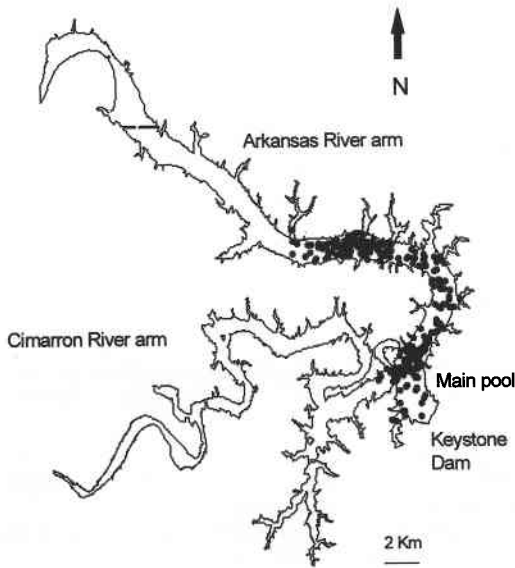


FIG. 1—Locations of transmitter-tagged paddlefish, *Polyodon spathula*, in Keystone Reservoir, Oklahoma, summer 1997.

were performed with SAS (Schlotzhauer and Littel, 1987); significance levels were set at  $P \leq 0.05$ .

**RESULTS**—Fish moved considerable distances (>500 m) soon after implantation. Because these movements were similar to movements encountered throughout the study, we assumed no short-term effects of surgery. All fish were located throughout the study period; however, not all fish were found during each 3-h interval. Fish congregated in the Arkansas River arm and the main pool of Keystone Reservoir. Although we searched the Cimarron River arm when we did not find all fish in other reservoir areas, we located no transmitter-tagged paddlefish upstream from the extreme lower Cimarron River arm (Fig. 1).

Water temperature, dissolved oxygen, and conductivity were recorded each sampling period in the Arkansas River arm and the main pool; however, these variables could not be recorded in the Cimarron River arm (the area not used by paddlefish) during all sampling periods because of time limitations. We were able to collect these data from the Cimarron arm for 17 to 19 June, 6 to 8 July, 28 to 30 July, and 10 to 12 August. From these data, we determined differences in water chemistry conditions between the two reservoir arms. Using

water chemistry data, we quantified available habitat within the reservoir where paddlefish were located throughout the study (Arkansas River arm and main pool). All water chemistry data were included in analyses of movement rate and distance from the dam. When water temperatures were uniform in the reservoir, we were unable to infer depth, DO, and conductivity from the temperature-sensing transmitters. Uniform nighttime temperatures occurred on all sampling periods except 10 to 12 August; thus, we excluded nighttime periods from our water chemistry selection analysis because of small sample size ( $n = 31$ ). All daytime periods exhibited thermal stratification and were used in all analyses.

**Movement and Distribution**—Paddlefish moved significantly more at night ( $\bar{X} = 784$  m/h,  $SD = 830$ ) than during the day ( $\bar{X} = 348$  m/h,  $SD = 248$ ;  $P < 0.001$ ). Movement rates were highly variable, ranging from near 0 m/h during the day to 4,007 m/h at night. Daytime movement rates ( $n = 120$ ) were not related to water level, inflow, or discharge (all  $r$ s between  $-0.03$  and  $-0.13$ , all  $P$ s  $> 0.165$ ); however, nighttime movement rates ( $n = 86$ ) were negatively related to discharge ( $r = -0.44$ ,  $P < 0.001$ , inflow ( $r = -0.41$ ,  $P < 0.001$ ) and water level ( $r = -0.57$ ,  $P < 0.001$ ). Although nighttime paddlefish movement was associated with decreased discharge, inflow, and water levels, all three hydrologic variables were correlated to each other (all  $r$ s  $> 0.48$ , all  $P$ s  $< 0.001$ ) in the movement rate analysis. Paddlefish showed no difference in movement rates upstream or downstream ( $P = 0.253$ ).

During the day ( $n = 93$ ), distribution of paddlefish (distance from the dam) in the reservoir was negatively related to water level ( $r = -0.59$ ,  $P < 0.001$ ) and discharge ( $r = -0.61$ ,  $P < 0.001$ ), and positively related to inflow ( $r = 0.53$ ,  $P < 0.001$ ). Similar relationships were found with paddlefish location at night ( $n = 70$ ) with water level ( $r = -0.60$ ,  $P < 0.001$ ) and inflow ( $r = 0.28$ ,  $P = 0.019$ ). However, the relationship between discharge and paddlefish distance from the dam at night was not significant ( $r = 0.20$ ,  $P = 0.091$ ). In this analysis, the three hydrologic variables were correlated for both day and night periods. Inflow was negatively related to water level ( $r = -0.41$ ,  $P < 0.001$ ,  $n = 93$ ) and discharge ( $r = -0.45$ ,  $P < 0.001$ ,  $n = 93$ ) during the day, and positively