Original Research Paper

Paddlefish Movement and Dam Passage in the Ohio and Kanawha Rivers Depend on River Conditions

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Article history
Received: 2 June 2026
Revised: 20 October 2026
Accepted: 1 November 2026

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Abstract: The population of Paddlefish (*Polyodon spathula*) has increased in the Ohio River drainage of Ohio and West Virginia due to stocking efforts of the past few decades. However, Paddlefish movement was minimally investigated in this region of their range. In fall 2022, five Paddlefish were captured and tagged with acoustic transmitters. Their movements through the Ohio River and several tributaries were monitored from April 2023 to July 2025. Paddlefish moved most in the spring and were largely stationary until water temperatures reached at least 9 °C. Using logistic regression, we determined that Paddlefish movement varied in relation to water temperature, gage height, and temperature change from the previous day. Peak probability of movement occurred during water temperatures around 21.9 °C, high gage height, and rising water temperatures (i.e., springtime high water events). Paddlefish directional movement probability depended on gage height, with the highest probability of upstream movement occurring at a gage height 8.9 ft higher than the median gage height. Sixty total lock and dam passage attempts were recorded with seven successful upstream and three successful downstream passages. Paddlefish generally attempted upstream passages during colder water and higher gage heights when compared to downstream passage attempts. Findings from this study could inform managers about Paddlefish movements in the region and inform potential conservation lockage timing.

Keywords: Paddlefish; Movement; Dam Passage; Ohio River

Introduction

Polyodon spathula (Walbaum in Artedi) (hereafter Paddlefish) is a large-bodied freshwater fish native to the Mississippi River basin, select gulf drainages, and the Great Lakes (Jennings and Zigler 2009). They are commercially important in the lower sections of the Ohio River, for which they are harvested for meat and caviar (MICRA 2023). They suffered great reductions in range and abundance during the late 18th century and 19th centuries, which can be attributed to multiple factors including dam construction, inundated spawning grounds, overharvest, and pollution (Carlson and Bonislawsky 1981; Unkenholz 1986; Gerken and Paukert 2009; Jennings and Zigler 2009). However, Paddlefish have been recovering in some areas of their range, including in the upper Ohio River, due to water quality improvements and stocking efforts (Jennings and Zigler 2009; Argent et al. 2016; Rice and Zimmerman 2019). In 1983, Paddlefish populations in West Virginia were reportedly still in decline; however, in 1994 and 2006 they were reportedly increasing (Bettoli et al. 2009).

Paddlefish are slow to mature, with females reaching sexual maturation at 6 years old in the

southern part of their range and around 14 years old in the northern part (Jennings and Zigler 2009). Males typically mature slightly earlier than females (Jennings and Zigler 2009). Paddlefish from Louisiana, Mississippi, and Arkansas are expected to be sexually mature at around 106.7 cm standard length (Adams 1942). Typical adult lengths in the upper Ohio River range from 100–160 cm standard length (Stauffer et al. 2016). Male Paddlefish can typically spawn every year, and females can spawn every one to seven years, depending on the region (Jennings and Zigler 2009). Paddlefish spawn in the spring and require a suite of specific conditions of photoperiod, water temperature, and water flow to be successful (Jennings and Zigler 2009). Peak spawning was observed after spikes in water level and in water temperatures around 10–19 °C, depending on location (Purkett 1961; Wallus 1986; O'Keefe et al. 2007; Miller et al. 2011). Sexually mature Paddlefish often make migrations to spawning locations, and migration onset is usually influenced by water temperature or river discharge (Jennings and Zigler 2009; Tripp et al. 2019a). In the upper Mississippi River, fish tended to move when water temperatures were around 10–22 °C (Fritts et al. 2024). Some studies found that movement also appeared to depend on river flows or gage height (Paukert and Fisher 2001; Zigler et al. 2003; Schwinghamer et al. 2019), or river discharge changes and suspended sediment (Firehammer and Scarnecchia 2006). Spring migrations are often upstream (Jennings and Zigler 2009; Tripp et al. 2019a), but downstream or variable spring migrations have also been recorded in some areas (Zigler et al. 2003).

The Ohio River and some major tributaries experienced a wave of lock and dam (L&D) construction in the late 1800s and early 1900s (Switzer 1931). Before alteration, the river was described as having shoals and sandbars, but dams and dredging were used to create a minimum nine-foot navigational channel (Barton 1957; Switzer 1931). While L&Ds make the movement of goods easier, the movement capabilities of fish are often hindered. Paddlefish are potamodromous so L&Ds provide a challenge to their movements and reproduction (Jennings and Zigler 2009). In addition, building dams and channelizing shipping lanes alter the natural state of rivers and can remove flow variations that are ecologically important for many aquatic species, including the Paddlefish (Unkenholz 1986; Poff et al. 1997; Poff et al. 2007; Gerken and Paukert 2009). While L&Ds are difficult for Paddlefish to traverse, multiple studies have documented passage. Some studies observed upstream and downstream passages (Turney et al. 2022; Southall and Hubert 1984; Zigler et al. 2003; Barry et al. 2007), while others only observed downstream passage (Moen et al. 1992; Welsh et al. 2024). Downstream passage may be less difficult than upstream passage, but both appear to inhibit Paddlefish movement. Interestingly, two Paddlefish stocked by the Pennsylvania Fish and Boat Commission were caught 675 river kilometers downstream in Kentucky (Argent et al. 2016), meaning they passed all the Ohio River L&Ds along the West Virginia border.

Tracking fish with telemetry is an increasingly popular method of studying fish behavior and how they use their surroundings. Telemetry techniques have advanced since the 1950s and are now used for a variety of research objectives (Jacoby and Piper 2023; Thorstad et al. 2013). Acoustic telemetry has become popular for aquatic studies, capitalizing on the properties of sound transmission underwater. Acoustic transmitters are placed in or on a fish and produce a unique frequency and pulse rate into the water. The sound is then recorded by an underwater receiver (i.e., hydrophone) (Thorstad et al. 2013). Acoustic telemetry is useful for answering questions about the migratory behavior of fish, especially where receiver networks can be spaced longitudinally in rivers, and upstream and downstream of barriers like L&Ds (Jacoby and Piper 2023; Thorstad et al. 2013). Several studies have used acoustic telemetry to track Paddlefish movements and dam passage (see review Tripp et al. 2019a).

Paddlefish were reintroduced in the upper Ohio River and Allegheny River in the 1990s and early 2000s. Fish were stocked in Pennsylvania, West Virginia, and New York by respective state agencies. Argent et al. (2016), who reviewed the reintroduction in Pennsylvania waters, noticed poor fish condition and low natural reproduction (only one larval fish) in the navigable sections of the Ohio and Allegheny rivers. A Paddlefish population continues to persist in the Ohio River along the West Virginia border, but self-sustainability is unknown. Understanding Paddlefish movements and activity may help managers strengthen the population. This study complements Welsh et al. (2024), a previous paper that analyzed Paddlefish movements throughout the R.C. Byrd Pool of the Ohio River from October 2022 to August 2023 and focused on residence times and annual activity levels. They reported high levels of mobility during

spring and a single downstream dam passage event at the R.C. Byrd L&D, but they did not analyze fish movement relative to river conditions and only observed very limited interactions with L&Ds. In our study, we use the same fish as Welsh et al. (2024) but include a longer study period and larger study area. Here, we aim to describe the factors that coincide with Paddlefish movements and L&D passage in the Ohio River along West Virginia's state border. This information would supplement Welsh et al. (2024) in informing managers about Paddlefish movement in the region and could inform decisions on enabling Paddlefish migration to potential spawning grounds.

Materials and Methods

Study Area

This study focuses on portions of the Ohio River along West Virginia's state border and select tributaries in West Virginia and Ohio (Figure 1). The study area includes the R. C. Byrd, Racine, and Belleville pools of the Ohio River, as well as portions of the Greenup and Willow Island pools. The study area also includes the lower Kanawha River (R.C. Byrd), Raccoon Creek (R.C. Byrd), Mill Creek (Racine) and the Hocking River (Belleville).

Fish Collection and Receiver Array

The Paddlefish used in this study were the same as those in Welsh et al. (2024), and their capture and tagging is documented in that paper. Paddlefish were tagged with ultrasonic transmitters (Vemco V16-6x-A69-9001) and released back into Raccoon Creek. Paddlefish positions were gathered from U.S. Fish and Wildlife Service (USFWS) and West Virginia Division of Natural Resources (WVDNR) owned receivers (Vemco VR2W, VR2Tx, and NexTrak R1) located along the Ohio River, Kanawha River, and select tributaries. The receiver array included a range of locations along the Ohio River, including receivers on the upstream and downstream sides of four Ohio River navigation L&Ds (R.C. Byrd, Racine, Belleville, and Willow Island). Receivers in the Greenup pool include those directly downstream of the R.C. Byrd L&D and one location farther downstream. Receivers in Willow Island pool only include receivers on the upstream side of the Willow Island L&D (Figure 1). The Winfield L&D on the Kanawha River did not have a receiver directly on the L&D but had receivers several river kilometers upstream and downstream.

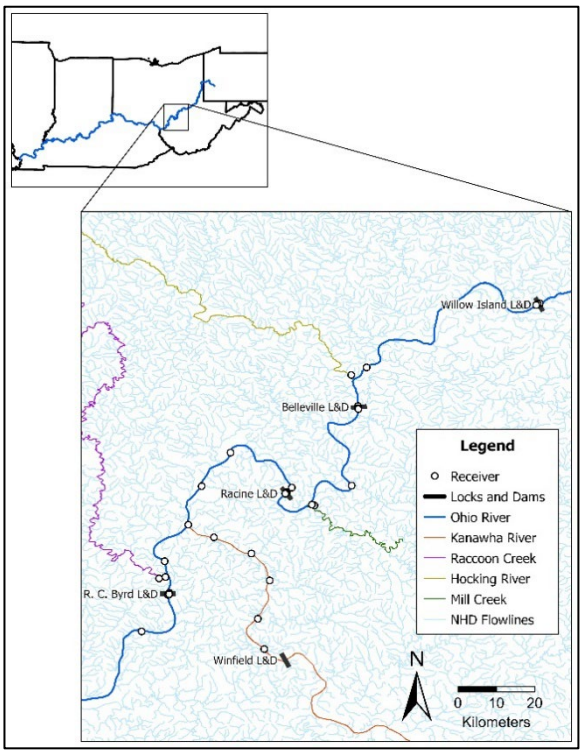


Figure 1. Study area. *Study area map of the Ohio River (blue) and select tributaries (Raccoon Creek – purple, Kanawha River – orange, Hocking River – yellow, and Mill Creek – green). Black bars denote locks and dams, open circles represent receivers, NHD = National Hydrography Dataset.*

The receiver data were downloaded by staff from USFWS and WVDNR. This study, which included receiver data between April 2, 2023, and July 13, 2025, included an approximately 27-month (833-day) dataset. The start date of the study was based on establishment of the complete array of receivers.

Daily Movement

We assigned each receiver location a river kilometer (rkm) measured as the distance to the receiver from the mouth of the Ohio River along the path of the National Hydrography Dataset (NHD). We used the same rkm for receivers that were very close to each other, due to the transmitter possibly signaling multiple receivers at the same time. For each fish, we included only datapoints where movement had occurred. This was defined as a situation where the fish's rkm had changed. For each movement, we calculated the change between the previously signaled receiver location and next signaled receiver location to determine the minimum distance traveled. Negative values indicated downstream movement and positive

values indicated upstream movement. We summarized the minimum distance traveled by each fish for each day and included minimum daily net movement (total) and minimum daily gross movement (directional). For days when no observations were made, we assessed movement at zero. For each day, we calculated the average minimum daily net movement (ADNM) and average minimum daily gross movement (ADGM) using all fish remaining in the study.

Dam Passage

We determined a successful dam passage by assessing if a transmitter signaled a receiver on the opposite side of a known Ohio River L&D location relative to the previous receiver position. We also differentiated passage direction as either upstream or downstream. We also recorded passage attempts. We defined upstream dam passage attempts as occurrences where a fish's presence was detected by a receiver on the downstream side of a dam. Downstream dam passage attempts were defined in a similar way except for the opposite direction. We also included successful passages as attempts. For each unsuccessful attempt we identified the initial time that the fish approached the dam (rounded down to the hour). For successful dam passages, we identified the time when the fish signaled a receiver located on the opposite side of the dam (rounded down to the hour).

Environmental Correlates Data

We gathered gage height and water temperature data from the U.S. Geological Survey (USGS) gage stations along the Ohio River for the time period of the study (U.S. Geological Survey, 2025). We downloaded these data using the dataRetrieval package in R (De Cicco et al. 2025). We gathered gage height in ft at the Point Pleasant, WV gage station (USGS-03201500). We chose to measure gage height in ft instead of converting to metric units because ft would be the units referenced by nearby managers for river height. Since discharge data were not available at any USGS gages in the study area, gage height served as an alternative to indicate river flow conditions. We gathered water temperature data in °C from the USGS gage at Ironton, OH (USGS-03216070). Although this gage is downstream of the R.C. Byrd Pool, we determined it to be the most comparable USGS water temperature gage for the study area. We averaged both gage height and water temperature by day and added these data to the daily movement data. We also classified gage height change (Gchange) as a categorical variable of "rise" or "fall," based on whether average daily gage height had increased or decreased since the previous day. We classified temperature change (Tchange) similarly to Gchange, where water temperature was categorized as "rise" or "fall." For dam passage analysis, we averaged the water temperature and gage height by hour and added to the dam passage data.

Modeling and Model Selection

Due to potential limitations of fish movement by L&Ds, we decided to assess the probability of movement using logistic regression rather than assessing distance moved. We defined movement as an instance where the ADGM was a non-zero value, indicating that at least one Paddlefish had moved that day. When ADGM was zero, we observed no Paddlefish movement, suggesting that all fish were stationary. Using logistic regression, we assessed movement ("movement" = 1 and "stationary" = 0) with a candidate set of models using combinations of average daily gage height, average daily water temperature, Gchange, and Tchange. We used Akaike information criterion (AIC) to determine competing models ($\Delta AIC \leq 2$) including the best approximating model ($\Delta AIC = 0$) (Burnham and Anderson 2002). However, averaging of competing models was not used for inference. For all days with observed movement, we assessed directionality (upstream movement = 1 and downstream movement = 0) using logistic regression and AIC model selection based on the same models as above. Both model selections were completed using the AICcmodavg R package (Mazerolle 2025). For dam passage analysis, which did not include model selection, we described conditions during upstream and downstream passage attempts. Due to issues with residual normality, we used Kruskal Wallace tests to assess differences in river conditions at the time of successful and unsuccessful passage attempts. In all statistical tests, significance was assessed as $p < 0.05$.

Results

Of the five fish in the study (Table 1), four of the fish were present within the study area for the entire study period. One fish (4678) possibly died, left the study area, or its tag was expelled or failed during the

spring of 2024. The last day 4678 signaled a receiver was May 5, 2024 in the Belleville Pool. Most of the Paddlefish were mobile throughout the study area, with three individuals leaving the R.C. Byrd Pool (Figure 2). Over the entire study period, the average total minimum gross movement observed was 1164.73 rkm per fish. The most active fish (4672) moved a gross total of 1852.62 rkm. The least active fish besides 4678 (fish 4671), moved a gross total of 995.53 rkm. Fish 4678 traveled at least 203.97 rkm up the Ohio River, and 4672 traveled at least 187.71 rkm. However, 4671 was only observed leaving the Kanawha River one time, after which it immediately returned.

Table 1. Capture dates and lengths of adult, telemetered Paddlefish from R.C. Byrd pool, Ohio and Kanawha Rivers, West Virginia. (adapted from Welsh et al. 2024)

Transmitter Number	Date of Capture	Eye-Fork Length (mm)
4671	10/4/2022	870
4672	10/3/2022	978
4678	11/4/2022	1029
4680	10/3/2022	1041
4681	10/4/2022	991

Table 2. Model selection statistics for predicting Paddlefish movement or immobility (A) and the model coefficients for the top model (B). Gchange = gage height change, Tchange = water temperature change, K = number of parameters, AIC = Akaike Information Criterion.

A

Model	K	AIC	Δ AIC
Gage+Temp^2+Tchange	5	897.6	0
Gage+Temp^2+Tchange+Gchange	6	899.5	1.90
Gage+Temp^2	4	903.29	5.69
Gage+Temp^2+Gchange	5	905.14	7.54
Temp^2	3	917.12	19.52
Gage+Temp+Tchange	4	925.62	28.01
Gage^2+Temp+Tchange	5	927.00	29.39
Gage^2+Temp+Tchange+Gchange	6	928.74	31.13
Gage+Temp	3	931.71	34.11
Gage^2+Temp	4	932.79	35.18
Gage+Temp+Gchange	4	933.45	35.84
Gage^2+Temp+Gchange	5	934.47	36.87
Temp+Tchange	3	939.10	41.49
Temp	2	945.85	48.25
Temp+Gchange	3	947.83	50.23
Gage+Tchange	3	980.41	82.81
Gage	2	987.01	89.40
Gage^2	3	987.97	90.37
Gage+Gchange	3	989.01	91.40
Intercept only	1	996.88	99.27

Coefficient	β1	β2	β3	β4	β5
Estimate	-7.905	-0.008	0.360	0.133	0.453
SE	1.119	0.002	0.058	0.035	0.164
P value	<0.001	<0.001	<0.001	<0.001	0.006

Equation:
logit(Moved) = β1 + β2*Temp^2 + β3temp + β4Gage + β5Tchange:Rising

Table 3. Model selection statistics for predicting Paddlefish movement directionality (A) and the model coefficients for the top model (B). Gchange = gage height change, Tchange = water temperature change, K = number of parameters, AIC = Akaike Information Criterion.

A

Model	K	AIC	Δ AIC
Gage^2	3	290.47	0
Gage^2+Temp+Gchange	5	292.26	1.78
Gage^2+Temp	4	292.30	1.82
Gage^2+Temp+Tchange	5	293.37	2.90
Gage^2+Temp+Tchange+Gchange	6	293.47	3.00
Gage+Gchange	3	297.99	7.52
Gage	2	298.07	7.60
Temp+Gchange	3	298.29	7.82
Temp+Gage+Gchange	4	299.02	8.55
Gage+Tchange	3	299.40	8.93
Temp	2	299.41	8.94
Gage+Temp^2+Gchange	5	299.60	9.13
Gage+Temp	3	299.61	9.14
Temp^2	3	299.81	9.33
Gage+Temp^2	4	300.26	9.79
Temp+Tchange	3	300.56	10.09
Gage+Temp+Tchange	4	300.84	10.36
Gage+Temp^2+Tchange+Gchange	6	301.36	10.88
Gage+Temp^2+Tchange	5	301.92	11.45
Intercept only	1	302.05	11.57

B

Coefficient	β1	β2	β3
Estimate	-33.796	-0.031	2.112
SE	11.321	0.011	0.723
P value	0.003	0.005	0.003

Equation:
logit(Upstream) = β1 + β2*Gage^2 + β3*Gage

Daily Movement

Daily movement was highly variable throughout the study period and appeared to be annually cyclic (Figure 3). There was a total of 237 days when ADGM was greater than zero, and 596 days when ADGM was zero. On days where movement occurred, the mean ADGM was 11.52 rkm (SD = 9.54) and the mean ADNM was -0.06 rkm (SD = 12.07). The greatest ADGM value was 55.72 rkm. Twenty models were fit using logistic regression to determine what river conditions predicted Paddlefish movement probability. The best approximating model (ΔAIC = 0) included gage height, a quadratic water temperature term, and Tchange, whereas a single competing model (ΔAIC = 1.9) was similar but also included Gchange (Table 2). The top model suggested a negative quadratic relationship between water temperature and

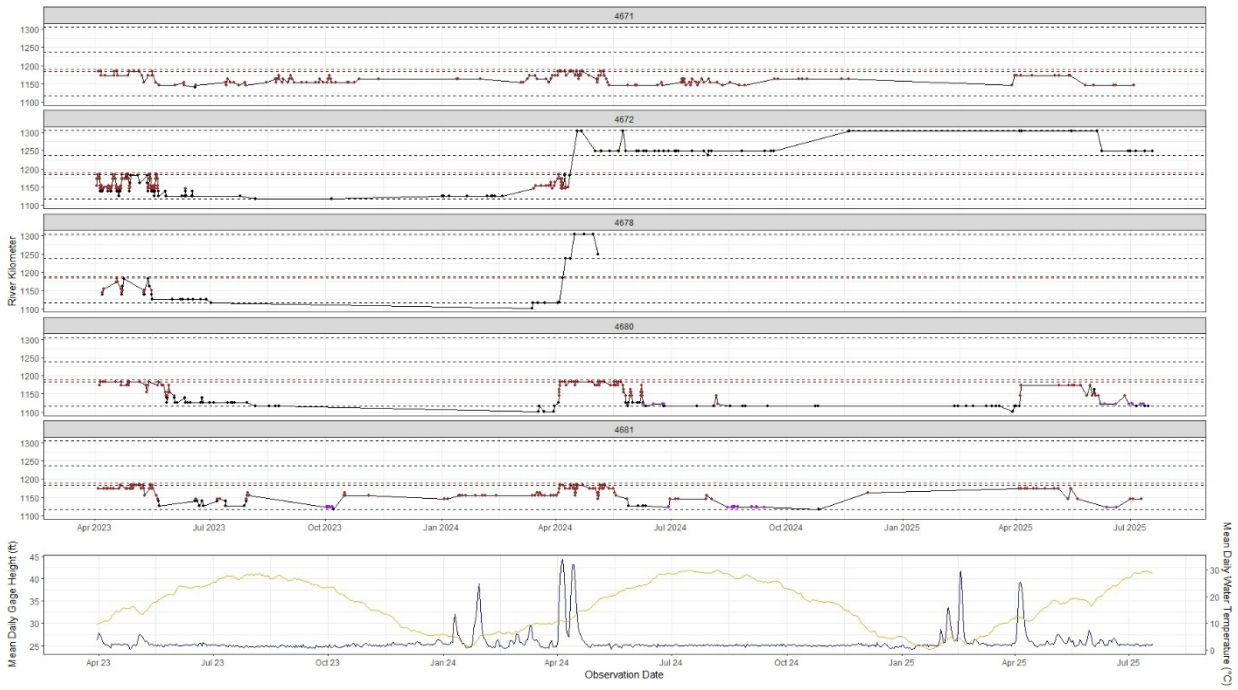


Figure 2. Summary of movement. *A summary of movements of each individual Paddlefish (faceted) in the study area. The waterbody is denoted by color (black = Ohio River, red = Kanawha River, purple = Raccoon Creek, and orange = Hocking River) and each point is located at the time and river kilometer when and where it was detected at a new receiver. Black horizontal dashed lines represent the river kilometers where lock and dams (L&Ds) exist on the Ohio River, and the red dashed line represents where the Winfield L&D exists on the Kanawha River. The bottom graph shows the mean daily gage height of the Ohio River at Point Pleasant, WV (blue) and the mean daily water temperature of the Ohio River at Ironton, OH (yellow) over the same time period.*

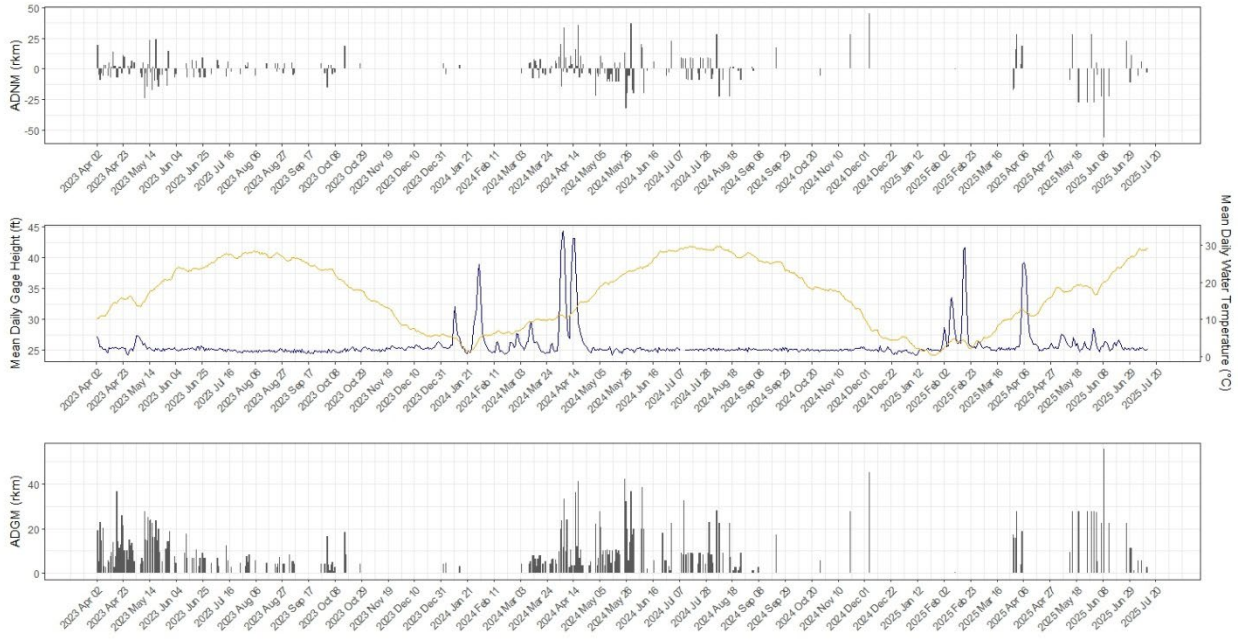


Figure 3. Average daily movements. *Daily movements of Paddlefish based on average minimum daily net movement (ADNM, top) and average minimum daily gross movement (ADGM, bottom). The middle plot shows the mean daily gage height of the Ohio River at Point Pleasant, WV (blue) and the mean daily water temperature of the Ohio River at Ironton, OH (yellow). All plots are on the same time frame for vertical comparisons.*

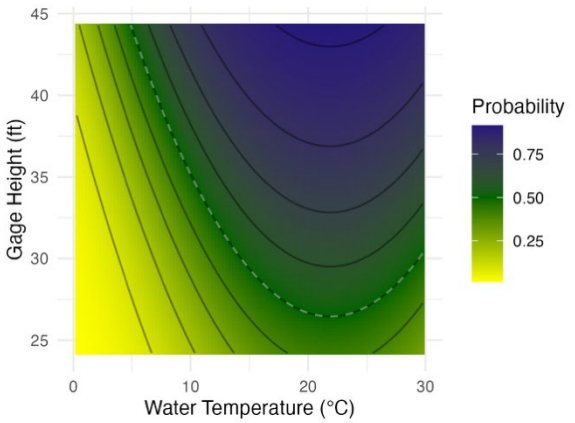


Figure 4. Predicted movement contour plot. Contour map of the predicted probability of Paddlefish movement shown across the observed range of water temperature and gage height (yellow = low probability, blue = high probability). This figure shows only predictions when water temperatures are rising (Tchange = "rise"). Black lines represent isolines of equal predicted probability, and the dashed isoline represents a 50 percent probability of movement.

probability of Paddlefish movement. This relationship was optimized at 21.87 °C (Figure 4). However, gage height also influenced probability of movement, with higher probabilities at higher gage heights. In addition, rising temperatures had a small additive increase in the probability of movement. Therefore, the greatest chances of Paddlefish movement were during high gage heights in water around 21.87 °C and rising water temperatures (Figures 4 and 5). These conditions seem to describe conditions of a springtime high water event. While the model suggested the highest probability of movement at higher temperatures, there seemed to be a threshold of around 9 °C for when Paddlefish movement was initiated (Figure 6). Of the days when movement occurred, 103 had positive ADNM values, and 114 had negative ADNM values. There were 20 days when ADGM was greater than zero, but ADNM was zero. These days were not included in this analysis. For days where ADNM was positive, the mean ADNM was 9.63 rkm (SD = 9.14) and the median was 5.72 rkm. For days when ADNM was negative, the mean ADNM was -8.82 rkm (SD = 8.11) and the median was -5.73 rkm.

The greatest magnitude ADNM values were -55.72 rkm and 45.36 rkm. The same suite of models as

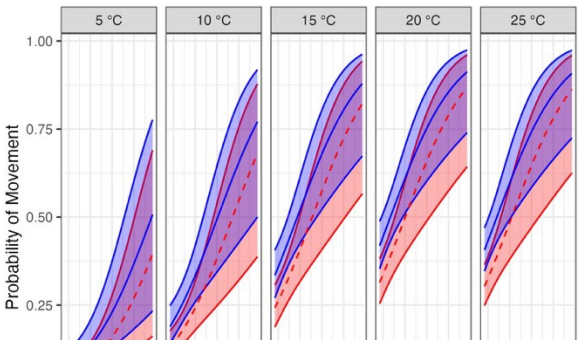


Figure 5. Predicted movement The predicted probability of any Paddlefish moving shown across the range of observed gage heights and faceted at five water temperatures. Solid blue lines indicate predictions for rising water temperatures and dashed red lines for falling water temperatures. The associated ribbons represent the 95% confidence intervals.

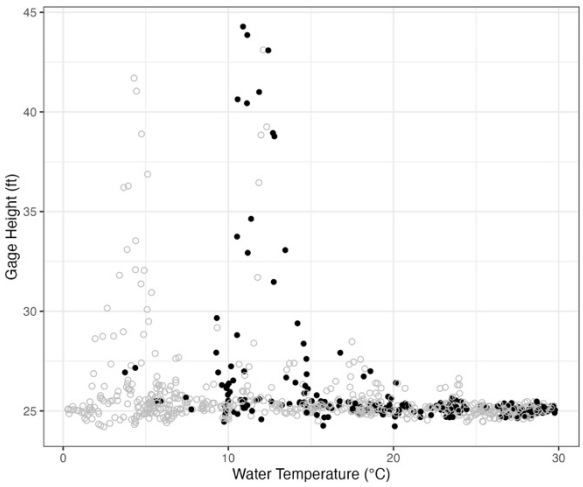


Figure 6. River conditions and movement. *Relationship between average daily water temperature and gage height for when average minimum daily gross movement (ADGM) of Paddlefish was either zero (hollow grey) or a non-zero value (solid black).*

above were fit to model movement directionality probability. The best approximating model included the single variable Gage2, but two competing additive effects models were Gage2+Temp+Gchange (ΔAIC = 1.78) and Gage2+Temp (ΔAIC = 1.82) (Table 3). The top model suggested a negative quadratic relationship between gage height and probability of upstream movement, a relationship that was optimized at a gage height of 34.03 ft (Figure 7), which is 8.87 ft higher than the median gage height of 25.16 ft.

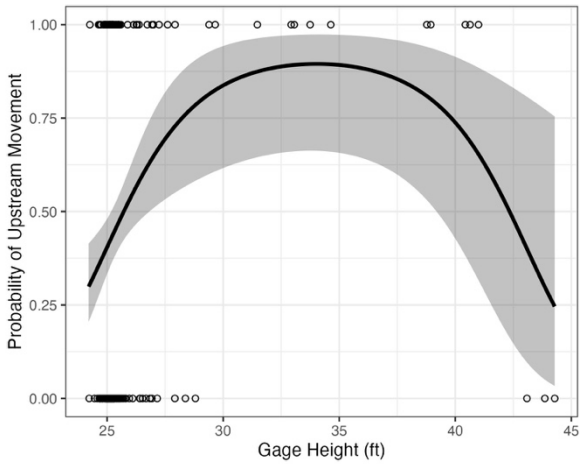


Figure 7. Predicted upstream movement. The predicted probability that the average minimum daily net movement (ADNM) of Paddlefish is upstream over the range of observed average daily gage heights during the study period. The ribbon represents the 95% confidence interval and black circles represent observations of either upstream (1) or downstream (0) ADNM.

Dam Passage

There was a total of 60 dam passage attempts (26 downstream and 34 upstream) during the study period. Of the downstream attempts, three were successful (11.5%), and of the upstream attempts, seven were successful (20.6%). All upstream passage attempts, and successful passages were done by three different fish. Downstream passage was attempted by four different fish, but only two fish were successful. One upstream dam passage was masked by a fish passing two dams while being undetected by receivers. This passage was not included in the following data but is listed above as a successful passage. Fish may have also attempted to pass the Winfield L&D, but we did not record these; and no passages past this L&D were recorded.

When compared to downstream passage attempts, Paddlefish made upstream passage attempts when gage height was on average 4.04 ft higher (average upstream attempt = 29.17 ft [SD = 5.48], average downstream attempt = 25.13 ft [SD = 0.40], $p < 0.001$) and water temperature was 13.80 °C cooler (average upstream attempt = 11.37 °C [SD = 4.18], average downstream attempt = 25.17 °C [SD = 5.50], $p < 0.001$) (Figure 8). The average gage height during successful upstream dam passages was 8.30 ft higher than that of unsuccessful upstream attempts (average success = 36.0 ft [SD = 4.82], average failure = 27.7 ft [SD = 4.45], p value = 0.002). Successful upstream dam passages occurred on average at a water temperature 0.89 °C warmer than unsuccessful upstream attempts (average success = 12.10 °C [SD = 1.48], average failure = 11.21 °C [SD = 4.56]). However, this difference was not significant ($p = 0.38$), and it appears that successful passages are nested within unsuccessful attempts, with all successes occurring between 10.5 - 14.4 °C. Successful downstream dam passages occurred on average at a gage height 0.83 ft higher than unsuccessful downstream attempts (average success = 25.87 ft [SD = 0.72], average failure = 25.04 ft [SD = 0.23], $p = 0.006$). Successful downstream dam passages occurred on average at a water temperature 7.08 °C cooler than unsuccessful attempts (average success = 18.90 °C [SD = 12.95], average failure = 25.98 °C [SD = 3.61]). However, this difference was not significant ($p = 0.21$) and the difference in averages is likely driven by one passage that occurred when water temperature was 4.0 °C.

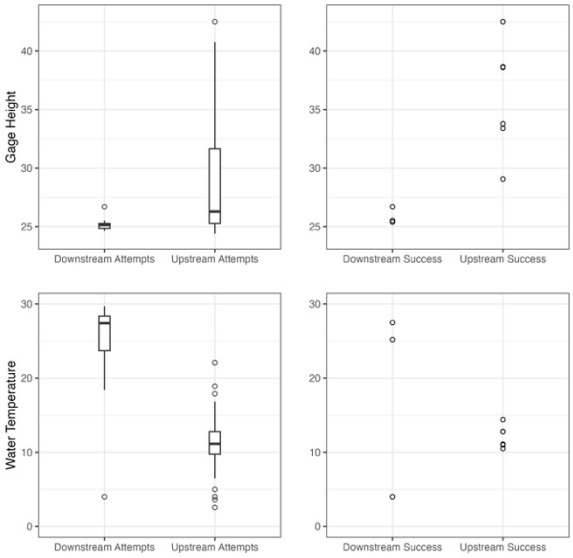


Figure 8. Dam passage. Boxplots of average hourly gage height (top left) and water temperature (bottom left) recorded during downstream and upstream dam passage attempts of Paddlefish. Boxes represent the 25 to 75% quantile, and the median is shown as the middle bar. Successful dam passages are plotted by average hourly gage height (top right) and average hourly water temperature (bottom right).

Discussion

Our acoustic transmitter study provided insights into the association of environmental correlates with Paddlefish movement in the upper Ohio River. Based on our average daily movement data, Paddlefish are most likely to move during high gage heights, intermediate water temperatures, and rising water temperatures. Water temperature appeared to play a stronger role than that of gage height in prompting Paddlefish to move. We also observed a threshold of water temperatures around 9 °C, below which Paddlefish were not likely to move. During 2024 and 2025, high flow events when water temperatures were cold (< 9 °C) did not prompt large amounts of movement. Our findings here are similar to those of Zigler et al. (2003), who observed Paddlefish in the Mississippi River, Wisconsin River, and Chippewa River moving during high water and at water temperatures around 10 °C. Our findings of movement onset were at slightly warmer temperatures than noted by Paukert and Fisher (2001), who described movement of Oklahoma Paddlefish above 6–8 °C. The Paddlefish in our study moved most in the spring and early summer, which is consistent with their spawning migrations and finding of Welsh et al. (2024). However, we also noticed movements outside of their

spawning migration period. Sex or age was not determined for Paddlefish in our study, data that would have provided additional insights regarding seasonal movement patterns. While Lein and Devries (1998) did not catch fish after water temperatures exceeded 18 °C, we observed Paddlefish moving well into the summer and in water temperatures up to 29.8 °C. While Tripp et al. (2019b) observed the most movement in the spring, they also noted high mobility in the summer. Gage height was an important variable in determining movement probability as well. This is also consistent with multiple studies noting movements during high flow periods (Paukert and Fisher 2001; Zigler et al. 2003; Firehammer and Scarnecchia 2006, Schwinghamer et al. 2019, Tripp et al. 2019b).

Regarding the direction of movement, gage height was the strongest explanatory variable. The highest probability of upstream movement occurred during intermediate gage heights. Predicted probability of upstream movement was over 75% when gages were between 28.25 and 39.82 ft, which is around 3.1 to 14.7 ft higher than the median gage height of 25.16 ft. Paukert and Fisher (2001) also noted upstream movements out of a reservoir during high flows and absence of movement in years where large spring flows did not occur. Firehammer and Scarnecchia (2006) noted that upstream Paddlefish movement in the Missouri and Yellowstone rivers was correlated to higher river discharge and suspended sediment, and noted downstream movements were correlated with decreasing flows and lower suspended sediment. Zigler et al. (2003) noted upstream and downstream Paddlefish migrations during springtime high flows in the Mississippi River; however, Chippewa and Wisconsin River Paddlefish generally migrated downstream. Barry et al. (2007) noted that after a large flood, juvenile Paddlefish were using current breaks downstream of where the Paddlefish were typically found. This finding may help to explain the quadratic relationship between gage height and movement direction we observed in our study, as Paddlefish may have sought downstream current breaks when flooding was too severe.

We documented seven successful upstream L&D passages and three successful downstream passages over our 27-month study period. Interestingly, we noted more upstream passages than downstream. Turney et al. (2022) also reported more upstream than downstream passages past one L&D in the upper Mississippi River. However, Zigler et al. (2003) noted more downstream than upstream passages and Moen et al. (1992) only reported downstream passage. Welsh et al. (2024) reported that the same fish in this study only had one downstream passage (past R.C. Byrd L&D, passage also included in this study) and no upstream passage events. Notably, during the Welsh et al. (2024) study time period, the maximum Point Pleasant gage height after the water temperature at the Ironton gage was over 9 °C, was only about 28 ft. Low flows during the Welsh et al. (2024) study and high flows during our study period could explain the differences between the passage frequency they observed and the one we observed.

Notably, in our study the upstream passages were completed by three fish, and six passages were completed in a very short time window (April 2024) during two consecutive high flow events (peaking at around 44.6 ft and 43.7 ft). During these flows, the L&Ds were likely inundated or fully open. Southall and Hubert (1984) suggested that Paddlefish have difficulty passing L&Ds in the upstream direction unless the gates are fully opened during high water periods. In several other studies, high river flows or low hydraulic head (differences between upstream and downstream water levels) seem to be the main factor in deciding upstream dam passage, allowing Paddlefish to pass when L&Ds are inundated or fully open (Zigler et al. 2004; Simcox et al. 2015; Hershey et al. 2022; Turney et al. 2022; Fritts et al. 2024). Upstream dam passages can also occur through lock usage, but typically these are less numerous than passages during open river conditions (Simcox et al. 2015; Hershey et al. 2022; Turney et al. 2022). Therefore, lockages for upstream passage may be more important during years of drought or for dams that do not typically reach open river conditions (Simcox et al. 2015; Fritts et al. 2024).

Upstream and downstream dam passage attempts occurred under different river conditions. Generally, fish attempted to pass upstream during intermediate water temperatures and a range of gage heights (Figure 8). However, downstream passage attempts were typically made during warm water temperatures and low gage heights, a characteristic of typical summer river conditions. This is not surprising based on our movement direction findings. Moen et al. (1992) noted that L&D passages occurred in either summer or fall for six fish that moved downstream. Also, Budnik et al. (2014) noted that downstream passages over the dam of the Allegheny Reservoir typically occurred in summer months.

Management Implications

Management implications of this study may be conditional on our acknowledgement of several caveats, including the small sample size of tagged individuals, the use of gage height as a proxy for river discharge, and the use of water temperature data from a geographically proximate location to the study area. While this study documents the movement behaviors of five Paddlefish, inference from these results and a broader application to the Ohio River Paddlefish population are limited by the small sample size. Thus, we consider our results in the context of a preliminary or pilot study, one that may inform future studies of movement patterns in the Ohio River Paddlefish population. We assumed that gage height of the river would be a valid proxy for river discharge. We used water temperature data from the U.S. Geological Survey gage at Ironton, Ohio, a location downstream of the study area.

Although this study is based on a small sample size (five fish), it has contributed to our understanding of Paddlefish ecology in the upper Ohio River. Tripp et al. (2019b) suggested that Paddlefish management may benefit from interjurisdictional or interstate collaborations. The high mobility of fish that we observed reiterates this suggestion. In addition, while there is frequent barge traffic associated with L&Ds on the upper Ohio and Kanawha rivers, it appears that these structures are still impeding Paddlefish movement. According to Turney et al. (2022), upstream passage should be more likely with more upstream traveling vessels. However, they also noted Paddlefish presence below dams is less likely with more downstream traveling barges (Turney et al. 2022). Also, in Pennsylvania juvenile Paddlefish were observed actively avoiding barges (Barry et al. 2007). These factors could potentially make lockages for barges less productive for Paddlefish passage. While lockages specifically designed for fish passage purposes in the Alabama River yielded a low passage rate (8%), they did pass more Paddlefish than navigational lockages (Simcox et al. 2015). Targeted conservation lockages could potentially help Paddlefish move more freely through the Ohio River. This study could help provide local information about when conservation lockages would be most effective for passing Paddlefish in the Ohio River. Based on our findings, lockages could be operated in the spring after temperatures reach 9 °C, and especially during heightened flows that are not enough to inundate the L&Ds.

Acknowledgements

This study was funded through the West Virginia Division of Natural Resources. Downloading and distribution of telemetry data were assisted by Lane Burton, Tyler Gross, MacKenzie Ullman, Corwyn Hall, Wyatt Jacobs, and Brennon Watt of the U.S. Fish and Wildlife Service, and Stephen Floyd of the West Virginia Division of Natural Resources. Paddlefish collections were assisted by Lane Burton and Brennon Watt. We also thank David Argent of Penn West University for reviewing the manuscript. At the time of publication, data were not publicly available from the West Virginia Division of Natural Resources. Contact Katherine.j.zipfel@wv.gov for data inquiry. This work was conducted under the auspices of West Virginia University IACUC protocol # 2204052691. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Literature Cited

Adams, L.A. 1942. *Age determination and rate of growth in Polyodon spathula, by means of the growth rings of the otoliths and dentary bone*. The American Midland Naturalist. **28**(3): 617–630. DOI:10.2307/2420893

Argent, D.G., W.G. Kimmel, R. Lorson, and M. Clancy. 2016. *An evaluation of interstate efforts to re-introduce Paddlefish to the upper Ohio River basin*. Northeastern Naturalist. **23**(4): 454–465. DOI:10.1656/045.023.0403

Barry, P.M., R.F. Carline, D.G. Argent, and W.G. Kimmel. 2007. *Movement and habitat use of stocked juvenile Paddlefish in the Ohio River system, Pennsylvania*. North American Journal of Fisheries Management. **27**(4): 1316–1325. DOI:10.1577/M06-232.1

Barton, T.F. 1957. *Twenty-five years' use of the 9-foot Ohio River channel*. Economic Geography. **33**(1): 41–49. DOI:10.2307/142566

Bettoli, P.W., J.A. Kerns, and G.D. Scholten. 2009. *Status of paddlefish in the United States*. American Fisheries Society Symposium. **66**: 23–38.

Budnik, R.R., M. Clancy, J.G. Miner, and W.D. Brown. 2014. *Assessment of Paddlefish reintroduction into Allegheny Reservoir*. North American Journal of Fisheries Management. **34**(5): 1055–1062. DOI:10.1080/02755947.2014.944679

Burnham, K.P. and D.R. Anderson. 2002. *Model selection and multimodel inference: A practical information-theoretic approach*. Springer-Verlag, New York. 488 pp.

Carlson, D.M. and P.S. Bonislawsky. 1981. *The Paddlefish (Polyodon spathula) fisheries of the midwestern United States*. Fisheries. **6**(2): 17–27. DOI:10.1577/1548-8446(1981)006%253C0017:TPPSFO%253E2.0.CO;2

De Cicco, L.A., R.M. Hirsch, D. Lorenz, W.D. Watkins, and M. Johnson. 2025, *dataRetrieval: R packages for discovering and*

retrieving water data available from federal hydrologic web services. v.2.7.20, DOI:10.5066/P9X4L3GE

Firehammer, J.A. and D.L. Scarnecchia. 2006. *Spring migratory movements by Paddlefish in natural and regulated river segments of the Missouri and Yellowstone rivers, North Dakota and Montana*. Transactions of the American Fisheries Society. **135**(1): 200–217. DOI:10.1577/T05-058.1

Fritts, M., D. Gibson-Reinemer, D. Appel, K. Lieder, C. Henderson, A. Milde, M. Brey, J. Lamer, D. Turney, Z. Witzel, E. Szott, G. Loppnow, J. Stiras, K. Zankle, D. Oliver, R.J. Hoxmeier, and A. Fritts. 2024. *Flooding and dam operations facilitate rapid upstream migrations of native and invasive fish species on a regulated large river.* Sci Rep. **14**(1): 20609. DOI:10.1038/s41598-024-70076-4

Gerken, J.E. and C.P. Paukert. 2009. *Threats to paddlefish habitat: implications for conservation*. American Fisheries Society Symposium. **66**: 174–183.

Hershey, H., D.R. DeVries, R.A. Wright, D. McKee, and D.L. Smith. 2022. *Evaluating fish passage and tailrace space use at a low-use low-head lock and dam*. Transactions of the American Fisheries Society. **151**(1): 50–71. DOI:10.1002/tafs.10330

Jacoby, D.M.P. and A.T. Piper. 2023. *What acoustic telemetry can and cannot tell us about fish biology*. Journal of Fish Biology. **106**(5): 1260–1284. DOI:10.1111/jfb.15588

Jennings, C.A. and S.J. Zigler. 2009. *Biology and life history of Paddlefish in North America: an update*. In: C.P. Paukert and G.D. Scholten (eds.), Paddlefish management, propagation, and conservation in the 21st century: building from 20 years of research and management. American Fisheries Society. p 1–22.

Lein, G.M., and Devries, D.R. 1998. *Paddlefish in the Alabama River drainage: population characteristics and the adult spawning migration*. Transactions of the American Fisheries Society. **127**(3): 441–454. DOI:10.1577/1548-8659(1998)127%253C0441:PITARD%253E2.0.CO;2

Mazerolle, M.J. 2025. *AICcmodavg: model selection and multimodel inference based on (Q)AIC(c)*. v.2.3-4, Available: https://cran.r-project.org/web/packages/AICcmodavg/index.html.

MICRA (Mississippi Interstate Cooperative Resource Association). 2023. *A summary report of cooperative inter-agency management activities and recommendations for commercial Paddlefish fisheries in the Mississippi and Ohio Rivers*. Paddlefish and Sturgeon Committee, Paddlefish Commercial Harvest States Workgroup. Mississippi Interstate Cooperative Resource Association. 45 pp.

Miller, S.E., D.L. Scarnecchia, and S.R. Fain. 2011. *Timing of Paddlefish spawning in the Upper Missouri River, Montana, USA in relation to river conditions*. Journal of Applied Ichthyology. **27**(6): 1291–1297. DOI:10.1111/j.1439-0426.2011.01894.x

Moen, C.T., D.L. Scarnecchia, and J.S. Ramsey. 1992. *Paddlefish movements and habitat use in pool 13 of the Upper Mississippi River during abnormally low river stages and discharges*. North American Journal of Fisheries Management. **12**(4): 744–751. DOI:10.1577/1548-8675(1992)012<0744:PMAHUI>2.3.CO;2

O'Keefe, D.M.,J.C. O'Keefe, and D.C. Jackson. 2007. *Factors influencing Paddlefish spawning in the Tombigbee Watershed*. Southeastern Naturalist. **6**(2): 321–332. DOI:10.1656/1528-7092(2007)6[321:FIPSIT]2.0.CO;2

Paukert, C.P., and W.L. Fisher. 2001. *Spring movements of Paddlefish in a prairie reservoir system*. Journal of Freshwater Ecology. **16**(1): 113–124. DOI:10.1080/02705060.2001.9663794

Poff, N. L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. *The natural flow regime*. BioScience. **47**(11): 769–784. DOI:10.2307/1313099

Poff, N.L., J.D. Olden, D.M. Merritt, and D.M. Pepin. 2007. *Homogenization of regional river dynamics by dams and global biodiversity implications*. Proceedings of the National Academy of Sciences. **104**(14): 5732–5737. DOI:10.1073/pnas.0609812104

Purkett, C.A. Jr., 1961. *Reproduction and early development of the Paddlefish*. Transactions of the American Fisheries Society. **90**(2): 125–129. DOI:10.1577/1548-8659(1961)90[125:RAEDOT]2.0.CO;2

Rice, D., and B. Zimmerman. 2019. *A naturalist's guide to the fishes of Ohio*. Ohio Biological Survey. 391 pp.

Schwinghamer, C.W., S. Tripp, and Q.E. Phelps. 2019. *Using ultrasonic telemetry to evaluate Paddlefish spawning behavior in Harry S. Truman Reservoir, Missouri*. North American Journal of Fisheries Management. **39**(2): 231–239. DOI:10.1002/nafm.10263

Simcox, B.L., DeVries, D.R., and Wright, R.A. (2015). *Migratory characteristics and passage of Paddlefish at two southeastern U.S. lock-and-dam systems.* Transactions of the American Fisheries Society, **144**(3): 456–466. DOI:10.1080/00028487.2014.995832

Southall, P.D., and W.A. Hubert. 1984. *Habitat use by adult Paddlefish in the Upper Mississippi River*. Transactions of the American Fisheries Society. **113**(2): 125–131. DOI:10.1577/1548-8659(1984)113<125:HUBAPI>2.0.CO;2

Stancill, W., G.R. Jordan, and C.P. Paukert. 2002. *Seasonal migration patterns and site fidelity of adult Paddlefish in Lake Francis Case, Missouri River*. North American Journal of Fisheries Management. **22**(3): 815–824. DOI:10.1577/1548-8675(2002)022<0815:SMPASF>2.0.CO;2

Stauffer, J.R., Jr., R.W. Criswell, and D.P. Fischer. 2016. *The fishes of Pennsylvania*. Cichlid Press. El Paso, TX. 556 pp.

Switzer, J.E. 1931. *The completed Ohio River project*. Proceedings of the Indiana Academy of Science. **41**: 339–350.

Thorstad, E.B., A.H. Rikardsen, A. Alp, and F. Økland. 2013. *The use of electronic tags in fish research – an overview of fish telemetry methods*. Turkish Journal of Fisheries and Aquatic Sciences. **13**(5): 881–896. DOI:10.4194/1303-2712-v13_5_13

Tripp, S.J., B.C. Neely, and R.J.H Hoxmeier. 2019. *Paddlefish migrations and movements: a review of tagging and telemetry studies*. In: Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society Symposium **88**; 49–65.

Tripp, S.J., Phelps, Q.E., Hupfeld, R.N., Herzog, D.P., Ostendorf, D.E., Moore, T.L., Brooks, R. C., and J.E. Garvey. 2019. *Sturgeon and Paddlefish Migration: Evidence to Support the Need for Interjurisdictional Management. Fisheries*, **44**(4): 183–193. DOI:10.1002/fsh.10215

Turney, D.D., A.K. Fritts, B.C. Knights, J.M. Vallazza, D.S. Appel, and J.T. Lamer. 2022. *Hydrological and lock operation conditions associated with Paddlefish and bigheaded carp dam passage on a large and small scale in the Upper Mississippi River (pools 14–18)*. PeerJ. 10:e13822. DOI:10.7717/peerj.13822

Unkenholz, D.G. 1986. *Effects of dams and other habitat alterations on Paddlefish sportfisheries*. In: J.G. Dillard, L.K. Graham, and T.R. Russell (eds.) The Paddlefish: status, management, and propagation. American Fisheries Society, North Central Division, Special Publication 7, Bethesda, Maryland. p 54-61.

U.S. Geological Survey. 2025. USGS Water Data for the Nation: U.S. Geological Survey National Water Information System database, accessed August 20, 2025, at https://doi.org/10.5066/F7P55KJN.

Wallus, R. 1986. *Paddlefish reproduction in the Cumberland and Tennessee River systems*. Transactions of the American Fisheries Society. **115**(3): 424–428. DOI:10.1577/1548-8659(1986)115<424:PRITCA>2.0.CO;2

Welsh, S.A., K.J. Zipfel, A.W. Peters, D.C. Hoffman, and C.M. Layne. 2024. *Paddlefish movement and dam passage in the Ohio and Kanawha Rivers, West Virginia*. Proceedings of the West Virginia Academy of Science. **96**(2). 12-19. DOI:10.55632/pwvas.v96i2.1103

Zigler, S.J., M.R. Dewey, B.C. Knights, A.L. Runstrom, and M.T. Steingraeber. 2003. *Movement and habitat use by radio-tagged Paddlefish in the Upper Mississippi River and tributaries*. North American Journal of Fisheries Management. **23**(1): 189–205. DOI:10.1577/1548-8675(2003)023<0189:MAHUBR>2.0.CO;2

Zigler, S.J., M.R. Dewey, B.C. Knights, A.L. Runstrom, and M.T. Steingraeber. 2004. *Hydrologic and hydraulic factors affecting passage of Paddlefish through dams in the Upper Mississippi River*. Transactions of the American Fisheries Society. **133**(1): 160–172. DOI:10.1577/T02-161