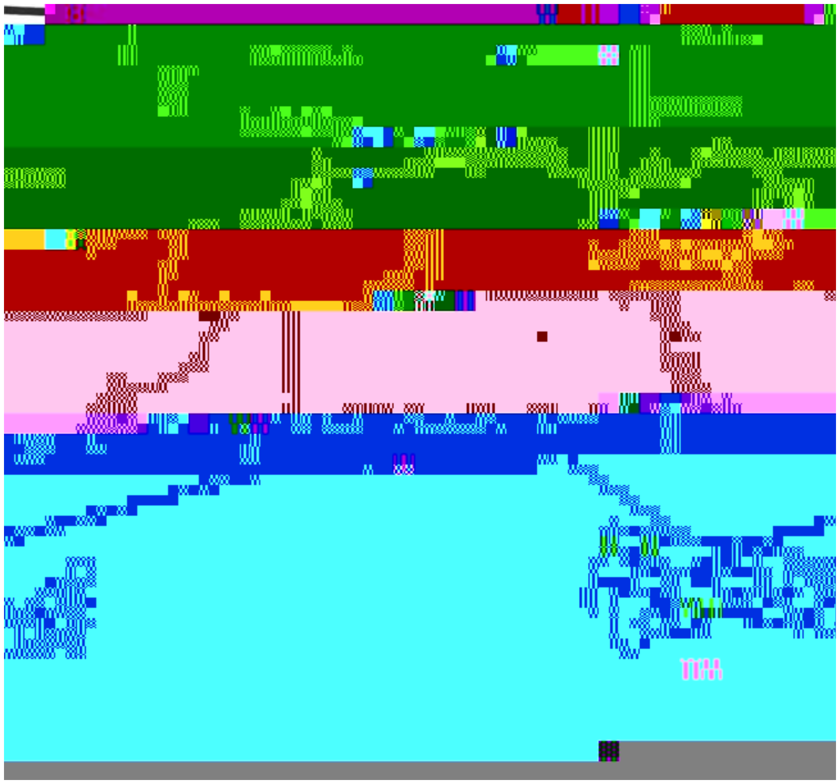
R[illegible] Paddlefish, [illegible], of the Yellowstone-Sakakawea stock, Missouri and Yellowstone Rivers, Montana and North Dakota, were radio-tagged to assess the influence of spring discharge on duration of river residency, ascent

Paukert and Fisher 2001), to access spawning in 1953. In spring, adults ascend through the reservoir headwaters and into the river in preparation for spawning. Paddlefish have access to about 375 river kilometers (rkm) of the Missouri River



Map of the study area including the lower Yellowstone River and the Missouri River from Fort Peck Dam to Lake Sakakawea, Montana and North Dakota. The filled circle represents the Intake diversion dam (Yellowstone River river kilometer 114), and the filled diamonds indicate the US Geological Survey gauging stations at Culbertson (Missouri River river kilometer 63) and Sidney (Yellowstone River river kilometer 47), Montana

during the study. Sex-specific large-diameter transmitters were used for fish tagged in the spring of 1999: large transmitters (14.5 cm long, 4.1 cm in diameter, and 265 g in weight) were implanted into females, whereas small transmitters (7.8 cm long, 4.1 cm in diameter, and 130 g in weight) were implanted into males. In comparison, the transmitters implanted into fish tagged in the fall of 1999 and 2000 were lighter (100 g), longer (17.0 cm), and of smaller diameter (2.0 cm) to accommodate a smaller incision and fewer sutures during surgeries. Radio transmitters weighed less than 2% of body weight for all tagged fish (Winter 1996).

We divided the study area into three manageable units that were surveyed primarily by boat using a directional loop antenna: (1) YRkm 114–YRkm 47; (2) YRkm 47–Confluence; and (3) a 40 km stretch extending downriver from the Confluence. Aerial surveys were conducted periodically, particularly along the MR above the Confluence due to its poor accessibility by boat. We surveyed the three study units weekly during the spring to determine the presence and location of individual fish along the river system. Geographical coordinates were recorded for all contacted fish using a global positioning system receiver and later overlaid onto a digitized map of the river system using geographic information systems software (ARC/INFO, Environmental Systems Research Institute, Inc., Redlands, California). During spring surveys, a tag that had been consecutively contacted in the same location along the river for a period longer than 30 days was assumed to have been expelled. Tracking was not conducted during the summer after fish were no longer contacted in the river (indicating their probable return to Lake Sakakawea) because the radio transmitters were not easily detected at reservoir depths. During the fall and winter, we conducted surveys below the Confluence to identify staging areas occupied by fish that would participate in the forthcoming spring migration; fish were surveyed only 1–4 times per month during this time because of lack of movement. We monitored river conditions during the study by obtaining daily YR discharge ($m^3\ s^{-1}$) from the United States Geological Survey (USGS) gauging station near Sidney, Montana (YRkm 47), and daily temperatures from a data logger positioned at YRkm 13.5.

Data analyses

We assessed the influence of the flow regime on the duration of the spawning migration by examining the dates at which individual fish were last contacted during the spring. The date of last contact, or exit time, for an individual fish was considered to represent either the premature termination of the migration, or a close approximation to spawning time as paddlefish have been found to move quickly back downriver after spawning (Russell 1986). Because the entire study area was not surveyed every day and survey dates differed among years, we assigned exit times to weekly periods to minimize bias when assessing differences among years. Ten weekly periods were delineated, the first period starting on May 1 and the last period ending on July 9. We qualitatively examined distributions of exit times for all 4 years by plotting Kaplan–Meier curves, which depicted the proportion of fish remaining in the river throughout annual survey periods (Allison 1995).

Event-time analysis, which has recently been used in fisheries research to model passage rates at dams (Castro-Santos and Haro 2003; Zigler et al. 2004; Naughton et al. 2005), permitted a closer examination of inter-annual differences in the weekly number of paddlefish exiting the river system (i.e., weekly exit rates). We employed a Cox proportional hazards regression (PHREG) model to explore the effects of the spring flow regime on weekly exit rates across survey years:

$$k_0 \quad \exp b_1 \; 1 \quad \cdots \quad b$$

where is the probability (hazard) of an individual fish

If a fish was not found to ascend the YR, it was assigned a negative value representing the number of rkm below the Confluence where it was contacted. We excluded fish from the analysis that were harvested, had presumably expelled their tags, or ascended the MR above the Confluence and thus not subjected to levels of YR discharge. Because non-normality was detected in the residuals, data were log-transformed after adding a scaling factor to every rkm to eliminate negative values. In addition to year, we initially included sex as a factor in the ANOVA model but found it to be insignificant (sex: = 0.08, df = 1, = 0.78; sex*year interaction: = 1.10, df = 3, = 0.36) and eliminated it from further analyses to include fish of unknown sex. Bartlett's test of equal variances was also performed on the data to examine annual differences in the dispersion of furthest contact rkm (Neter et al. 1990).

We used linear regression to examine fidelity to potential spawning reaches for fish that participated in two migrations. Furthest upriver contacts from subsequent migrations were regressed on furthest upriver contacts from initial migrations while setting the intercept parameter to zero. An estimated slope parameter that was not significantly different from unity would indicate that individual fish migrated to similar reaches in different years. In other words, fish that had migrated far up the YR were likely to return to distant sites up the YR, whereas fish that had limited their migration to YR reaches near the Confluence were likely to return to these same downriver sites. We assessed fidelity to particular staging areas by qualitatively examining the relative distribution of contacts in reaches below the Confluence during fall and winter survey periods.

The annual profiles of the YR spring flow regime exhibited both similarities and differences among study years (Fig. 2). Generally, the longest periods of increasing discharge occurred from late May to early June in all 4 years. However, fluctuations in YR discharge were less prevalent in 1999 and 2000 than in 2001. During 1999 and 2000, discharge increased for periods of at least 10 days, whereas periods of continuously rising discharge lasted no longer than 6 days during 2001. Peak discharge during the study was much higher in 1999 (1509 $m^3\ s^{-1}$) than in 2001 (680 $m^3\ s^{-1}$) with intermediate levels recorded in 2000 (997 $m^3\ s^{-1}$) and 2002 (1093 $m^3\ s^{-1}$). However, all 4 years exhibited peak flows below the median YR peak flow recorded over the last 50 years. Maximum spring discharge in 1999–2002 represented the 49th, 18th, 2nd, and 33rd percentiles, respectively.

We contacted 62 of the 69 (90%) radio-tagged paddlefish during the study, the number of contacted fish ranging between 19 and 26 in spring survey periods of 1999–2002. Twenty-five fish (17 males, 7 females, and 1 fish of unknown sex) were contacted in at least two of the four spring migrations with 3 of these 25 contacted in three different migrations. Females were contacted every 2 or 3 years, and males were typically contacted every other year or in successive years; the seven males contacted in consecutive migrations were all contacted in 2001 and 2002. A total of 695 contacts was recorded, the number of contacts ranging between 1 and 23 for individual fish. We contacted fish more frequently in 2000 (median, 10.5 contacts) and 2001 (median, 8.5 contacts) than in 1999 (median, 4 contacts) and 2002 (median, 4.5 contacts). In 1999 and 2000, we did not contact paddlefish in repeat surveys during July, suggesting their return to the reservoir by this time; five fish were still present in the river system in each of 2001 and 2002 during final surveys conducted on June 21 and July 1, respectively. We concluded that six of the 62 fish expelled their transmitters during their spring upriver migrations. In addition, five males and one female were harvested in North Dakota and Montana sport fisheries during the study.

Radio-tagged paddlefish generally remained in the river system for similar periods in all 4 years. Few fish exited early in each spring; 91, 74, 76, and 86% of the fish were still contacted in the river system on May 29 in 1999–2002 (Fig. 3). In addition, many fish exited during June in all 4 years in association with peak periods of YR discharge and river temperatures in excess of 13 C (Fig. 2). Ninety-one, 61, 51, and 58% of the fish were last contacted during June in 1999–2002 (Fig. 3). Results from the PHREG model corroborated the lack of detectable annual differences in migration duration. The rates at which fish exited in any given week were not significantly different among years over the survey weeks (PHREG, Likelihood ratio = 1.086, df = 3, = 0.78).

We detected fine-scale differences in exit patterns, however 4(howeiWm71h)-6.4(-sc71hBliC-l 4(h39.7(differecE)-9.3ces)4297.8(in)-983.6(the)]TJ0 -1.2519 TD[pre

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weeks-3241.1(in)-228.2(Jun,n)-22836(signi(cao)-.3(tly)-201(mere)3199.2(fish)-20867(wer)-7.4(e)31994(founde)]TJT*[

ringin

— 1999   – – 2000   · ·· 2001   – · – 2002

1.00
0.90
0.80
0.70
0.60
0.50

Percentage remaining in river system

May 1 May 8 May 15 May 22 May 29 June 5 June 12 June 19 June 26 July 3

Weekly periods

Year did not have a significant effect on either the mean (ANOVA, = 2.12, df = 3, = 0.106) or dispersion (Bartlett's test, v^2 = 1.53, df = 3, = 0.68) of furthest upriver contacts for migratory paddlefish. In both high and low flow years, many of the fish limited their ascent to the lower

55 rkm of the YR (Fig. 4); 65 of the 74 (88%) migrants that provided useful data on ascent distance were not contacted further upriver than YRkm 55. In addition, 11 of the furthest upriver

despite annual differences in YR spring flow regimes is not consistent with what is expected suggests a triggering of reproductive activity associated with peak river discharge, a relationship similar to that found in other paddlefish unique site-specific cues would have to be imprinted upon at an early life stage because larvae are swept downriver away from incubation areas

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