ECOLOGY OF A REINTRODUCED POPULATION

OF PADDLEFISH, *POLYODON SPATHULA*,

IN LAKE TEXOMA

By

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CHAPTER I

INTRODUCTION

Paddlefish *Polyodon spathula* have historically occurred in the Arkansas River and the Red River drainages of Oklahoma. In the Arkansas River drainage, paddlefish have been documented as far west as Great Salt Plains Reservoir, and in the upper Red River drainage they have been found in the Wichita (Pitman 1991), Washita, Clear and Muddy Boggy, Kiamichi and Little Rivers (Miller and Robinson 2004). Paddlefish populations have been studied extensively throughout the Arkansas River drainage in Oklahoma (Houser and Bross 1959, Houser 1965, Combs 1982, Ambler 1987, Ambler 1994, Paukert and Fisher 2001a, Gordon 2004); however, there have only been limited investigations in the Red River drainage between Oklahoma and Texas (Brent Bristow, United State Fish and Wildlife Service, personal communication, Paul Mauck, Oklahoma Department of Wildlife Conservation, Pitman 1991).

The range of the paddlefish has declined throughout the United States since the early 1900s because of destruction of spawning grounds, blockage of movements by dams, channelization and elimination of backwater areas, dewatering of streams, industrial pollution, and overharvest (Carlson and Bonislawsky 1981). The construction and closing of Denison Dam in 1944 on the mainstem Red River in southcentral Oklahoma blocked upstream migrations to spawning grounds and led to extirpation of the paddlefish from Lake Texoma and upstream. Although other natural populations in Oklahoma had been sustained above the closure of dams (Keystone and Grand Reservoirs), no paddlefish were ever recorded above Denison Dam (Pitman 1991).

The United States Fish and Wildlife Service (USFWS) initiated a restoration stocking program for paddlefish in Lake Texoma in 1999, stocking approximately 119,000 254-305-mm TL fingerlings through 2007 (Table 1). It was believed that Lake Texoma provides the habitats needed for the paddlefish population to become self-sustaining. However, subsequent annual netting surveys conducted by the USFWS indicated that paddlefish abundance in Lake Texoma was below that from other restoration stocking program in Kaw and Oologah Reservoirs in northern Oklahoma (Brent Bristow, USFWS, personal communication). Possible causes for the low abundance in Lake Texoma are predation on recently stocked paddlefish fingerlings by large predators (Parken and Scarnecchia 2002) and escapement through the dam during periods of high flows (Russell 1986).

Natural reproduction was anticipated in Lake Texoma after individuals from the early paddlefish stockings had reached sexual maturity and when flows were favorable for paddlefish to reach spawning areas. The three environmental cues for paddlefish reproduction are photoperiod, water temperature, and flow (Russell 1986). Paukert and Fisher (2001b) found flow to be more important than temperature or photoperiod in Keystone Reservoir, Oklahoma. They suggested that suitable spawning substrate may be a limiting factor for successful reproduction in prairie river systems such as the Arkansas River and Red River. Paddlefish move upstream when water temperatures reach 10-17°C (Pitman 1991) and spawn over 12.7-mm to 38.1-mm diameter gravel (Purkett 1961).

Baker et al. (2009) identified three gravel bars in the Red River and two in the Washita River above Lake Texoma where striped bass *Morone saxatilis* successfully spawned. It is possible that paddlefish in Lake Texoma could use these same areas to reproduce.

Seasonal movements and distribution of reservoir populations of paddlefish are similar to those of riverine populations. Paddlefish in Lake Francis Case, South Dakota, congregate in the upper end of the lake during the prespawning period, spawn, and then migrate to the lower reaches of the reservoir where they remain during the postspawning period and winter (Stancill et al. 2002). Paukert and Fisher (2000) described a similar migration pattern for paddlefish in Keystone Reservoir in northcentral Oklahoma, and suggested abiotic factors (water level and inflow) influenced their distribution during summer. They also found paddlefish avoided areas of the reservoir with high temperature or salinity.

The primary management needs for paddlefish on Lake Texoma are to determine their distribution, reproductive activity, and abundance. Defining the distribution of the population is needed so fisheries managers can develop efficient and representative sampling programs to perform stock assessments (Hubert 1999, Millspaugh and Marzluff 2001). Verifying a spawning run and identifying successful recruitment is the first step in evaluating if a self-sustaining population exists that is capable of supporting a sport fishery.

To address these concerns, the objectives of this study were to: 1) determine the distribution and movement patterns, 2) document spawning migrations and locate spawning areas, and 3) estimate the population size, growth rates, body condition, year class strength and mortality of paddlefish in Lake Texoma. This information will help evaluate the success of the recent restoration efforts.

CHAPTER II

STUDY AREA

Lake Texoma is a 36,000-ha impoundment of the Red and Washita rivers on the Oklahoma-Texas border with a watershed covering 102,870 km^2 in southwest Oklahoma and north Texas (Matthews et al. 1985). The lake has 933.4 km of shoreline and holds 3.3×10^8 m^3 of water with an average depth of 9.3 m at normal pool. Surface temperatures range from about 7°C in January-February to 30°C in August-September. The reservoir stratifies from late June through September, causing oxygen to be absent from the hypolimnion (Hubbs et al. 1976). Conductivity is influenced by the relatively high salinity of tributaries in the upper Red River.

The Red River originates in West Texas and enters Lake Texoma from the west. It is classified as a braided prairie river that has an average discharge of 90 m^3/s with peak discharges in the months of May and June. Conductivities greater than 4,000 *u*mhos are common in the Red River less than 50 km upstream of the reservoir (Matthews et al. 1985). The Washita River is more entrenched, entering the lake from the north with an average discharge of 44 m^3/s. Its conductivity of 400-1000 *u*mhos (Matthews et al. 1985) is more typical of streams and rivers in western Oklahoma.

CHAPTER III

METHODS

Movements and Distribution

Paddlefish were collected from January through March 2007 and December through February 2008 in the upper arms of the lake where USFWS biologists have had success gillnetting paddlefish in their annual surveys. Sinking gill nets of 152-mm bar-mesh monofilament (91 m long and 5.5 m deep) were used to target adult paddlefish. Two nets tied together perpendicular to the river channel or shoreline were suspended 1.5 m below the surface to prevent entanglement with boat traffic. Nets were fished overnight 16 to 20 h. When water temperature increased above 10°C, gillnetting was discontinued due to concerns of increased mortality (Gordon 2004).

Paddlefish collected were measured from the anterior orbit of the eye to the fork of the tail (mm, EFL; Ruelle and Hudson 1977), and weighed (kg). Sex was not determined because external characteristics are not reliable for distinguishing the sex of a paddlefish (Graham et al. 1986). Thirty adult paddlefish, 14 in 2007 and 16 in 2008 (Table 2), were surgically implanted with ultrasonic depth-sensing transmitters (model DT-97-L, Sonotronics, Tuscon, AZ) in the peritoneal cavity following recommendations by Hart and Summerfelt (1975). Each transmitter emitted a unique aural code and pulse interval between 69 kHz and 83 kHz to identify the fish and fish depth. These depth transmitters had an approximate battery life of 14 months. Each paddlefish was also fitted with a numbered #16 monel jaw tag on the anterior portion of the mandible and subsequently released near the capture site.

Tracking began the week following transmitter implantation and continued throughout the year. Because of the large size of Lake Texoma, search efforts alternated between the Red River arm and Washita River arm each week, as circumstances permitted. Paddlefish transmitters were located with a digital receiver (Sonotronics model USR-96) and directional hydrophone (Sonotronics model DH-4). When a fish was first encountered, the receiver's detection frequency was increased by 0.25 kHz to reduce signal strength and better pinpoint the fish. A paddlefish's location was determined when the signal could be heard equally in all directions (Paukert 2001b). The total depth, depth of fish, surface temperature, temperature and dissolved oxygen at fish depth (OxyGuard Beta meter), geographic coordinates (latitude and longitude obtained by Lowrance LCX-25 GPS combo depth finder), and time were recorded at each location. All data collected were entered into Microsoft Excel, and then transferred to ESRI ArcGIS 9.2 to analyze locations, seasonal movements, and home ranges.

To determine fish distribution, the reservoir was first divided into three sections, the Upper Red River arm, Upper Washita River arm, and lower lake (Figure 1). The upper sections were defined as having a maximum channel depth of less than 20 m. These sections were more riverine in nature, had higher productivity, and tended to stay more turbid (Oklahoma Water Resources Board 2009). The lower section was defined as having a minimum channel depth of 20 m and a lacustrine environment.

Chi-square tests were used to determine the distribution of paddlefish among the three sections of the lake in 2007 and 2008. To determine if individual fish were using the three sections in similar fashion, the log-likelihood test statistic (χ^2_{L1}) was used

$$\chi^2_{L1} = 2\sum_{j=1}^{n}\sum_{i=1}^{l} u_{ij} \log_e[u_{ij} / E(u_{ij})]$$

where u_{ij} is the amount of section *i* used by fish *j* and $E(u_{ij}) = u_{i+}u_{+j}/u_{++}$ in which u_{i+} is the number of locations in section *i* by all fish, u_{+j} is the total number of locations in all sections by fish *j*, and u_{++} is the total number of all section locations by all fish (Rodgers and White 2007). To determine if paddlefish selected for specific sections, a second log-likelihood test statistic was used

$$\chi^2_{L2} = 2\sum_{j=1}^{n}\sum_{i=1}^{l} u_{ij} \log_e[u_{ij} / E(u_{ij})]$$

where $E(u_{ij}) = \pi_i u_{+j}$ in which π_i is the proportion of area in section *i*. (Rodgers and White 2007). Once it was determined that fish were selecting for certain sections of the lake, selection ratios (Manly et at. 1993) were used to determine which sections of the lake were being selected, which was estimated by

$$\hat{w}_i = u_{i+} / (\pi_i u_{++}).$$

Values of $\hat{w}_i$ greater than one suggest that fish were selecting for that section of the lake while values less than one suggest avoidance. Simultaneous 95% Bonferroni-adjusted confidence intervals were also calculated for each section.

Although the distribution of paddlefish was not analyzed by season because of sparse data, linear home range was analyzed among four seasons. Spring was defined as the months of March through May, which included the spawning season, while summer and fall were June through August and September through November, respectively. The winter season, December through February, coincided with our winter netting when water temperatures were typically below 10°C.

Linear home range was defined as the shortest distance between the two outermost locations in a given season (Zigler et al. 2003). Means were not normally distributed; therefore a natural-log transformation was used to normalize data. A mixed model analysis of variance (ANOVA), where individual fish were designated as a random variable was performed to determine differences in seasons and years ($\alpha = 0.05$).

Population Dynamics

In addition to collecting paddlefish to implant with transmitters, a stratified random sampling design was used to collect data for population estimates in 2008 and 2009. Paddlefish data were collected from two areas in the reservoir, the Red River arm and Washita River arm. Sampling was once again concentrated in the up-lake portions of each arm. Each area was divided into eight 1.6-km sections along the river channel. Sections that did not have a maximum depth of 8 m were excluded because they were too shallow for the nets. Four randomly selected sections (i.e., the number of sections fishable in one day) of each area were gillnetted with two nets twice monthly from December through February in 2008 and 2009. Gill nets for paddlefish have been found to lack size selectivity (Scholten and Bettoli 2007). In addition, Paukert and Fisher (1999) found the 152-mm bar mesh had the highest median catch rate and collected all sizes of paddlefish. Consequently, 152-mm bar mesh monofilament sinking gill nets 91 m long and 5.5 m deep were used in this study to collect paddlefish.

Paddlefish collected were measured (mm; EFL), and weighed (kg). Sex was determined only from fish that died in the net. Because all paddlefish originally stocked into Lake Texoma were implanted in the rostrum with a coded wire tag at the Tishomingo National Fish Hatchery, the coded wire tag was removed after capture to identify the year class for length-at-age analysis. Each paddlefish caught was fitted with a numbered, #16 monel jaw tag on the anterior portion of the mandible and released near the capture site.

A modified Schnabel mark-recapture method was used to estimate population size (Krebs 1999). To calculate 95% confidence intervals, the Poisson distribution was used because we had less than 50 recaptures (Krebs 1999). We also measured relative weight (W_r; Brown and Murphy 1993) to describe body condition. Because all fish tagged with coded wire tags were of known age, mean length-at-age was estimated. Year-class strength and annual mortality were determined from catch curve data, where mortality was calculated as the natural log of abundance (number at age) regressed against age (Van Den Avyle and Hayward 1999). Catch rates were reported as the number of fish per 24-h set.

<u>Reproduction</u>

Four stationary submersible receivers (Sonotronics, SUR 1) were deployed 20 December 2007, two each in the Red and Washita rivers (Figure 1) to track upstream and downstream movements during the spring 2008 spawning migration. Of the two receivers placed in the Red River, one was located near the confluence of the river and the reservoir while the other was deployed at Addington Bend, 41 river km above the lake. One of the receivers in the Washita River was also positioned near the reservoir headwaters while the other was placed near the U.S. Highway 377 Bridge at Tishomingo, 37 river km above the lake. Once paddlefish were suspected to have entered the rivers, attempts were made to locate fish with a manual receiver and directional hydrophone. Areas of presumed spawning locations were also electrofished in an attempt to verify reproductive activity.

CHAPTER IV

RESULTS

Movements and Distribution

Over two years (2007 and 2008), we manually recorded 289 paddlefish locations (Figure 2). Sixty-eight percent (19 of 28) of the tagged fish inhabited both river arms. Twenty-eight percent (8 of 28) were detected in only the Red River arm while one fish (4%) was detected in only the Washita River arm. Individual fish selected different sections of the reservoir in both 2007 (X^2_{L1} = 110.55, P<0.0001) and 2008 (X^2_{L1} = 115.63, P<0.0001).

Of the 14 paddlefish implanted with transmitters during the winter of 2007, 12 were collected in the Red River arm while only two were collected in the Washita River arm. This was due to low catch rates of paddlefish in the Washita River arm, which is consistent with previous annual surveys (Bristow, personal communication). There were no confirmed mortalities during 2007 for fish implanted with transmitters, although two fish (tags 5 and 24) were never found after floods during July and August of 2007. On 7 July through 17 July 2007 water levels at Lake Texoma were 6.4 m above normal, causing water to run over the spillway for only the third time in the history of the reservoir (Figure 3). We were unable to track paddlefish from 19 June until 30 July due to limited lake access because of high water. Another paddlefish (tag 6) was last located in the reservoir 24 August 2007 after water levels had almost returned to normal pool but was not found the remainder of the year. These three paddlefish were presumed to have left the study area, either escaping through Denison Dam or migrating up the Washita or Red Rivers.

Six fish (tags 2, 3, 6, 18, 22, and 31) tagged in the Red River arm migrated down-lake as water temperatures rose. In September, as water temperatures cooled, most of these paddlefish moved back to the upper portions (Figure 4). Four fish (tag 8, 24, 34, and 43) stayed primarily in the upper half of the Red River arm the entire year (Figure 5). The fish with tag 11 was also regularly found in the upper half of the Red River arm but moved down lake in December 2007 (Figure 6). The other paddlefish tagged in the Red River arm (tag 5) was always found in the upper end of the Washita River arm before presumably leaving the study area during the flood (Figure 6).

Of the two paddlefish tagged in the Washita River arm, one fish (tag 13) remained in the upper end of the Washita River arm the entire year. The other fish (tag 20) was also routinely found in the upper end of the Washita River arm, except for 4 June 2007 when it was located mid lake on the Red River arm after traveling 30.4 km in three days (Figure 7).

In 2008, sixteen paddlefish were implanted with ultrasonic transmitters. Thirteen fish were collected on the Red River arm and only three on the Washita River arm. This was again due to higher catch rates of large paddlefish (> 900 mm EFL) on the Red River arm. One fish (tag 83) was confirmed dead 67 days after implantation while two others (tags 29 and 91) were never located in the reservoir. Consequently, we tracked only 13 paddlefish during 2008.

Although some fish in 2007 migrated downstream as water temperatures increase, paddlefish in 2008 paddlefish did not. Ten of the 13 (76.9%) fish tagged in the Red River arm inhabited both river arms at some point during the year; most of these locations came from the upper ends of the two river arms (Figure 8). Of the other three fish, one was never found (tag 29) while the other two (tags 78 and 81) were only located in the Red River arm (Figure 9).

Two fish (tags 80 and 96) implanted on the Washita River arm in 2008 were found in both arms of the reservoir, although most of their locations were found in the upper reaches of the Washita River arm (Figure 10). The other fish implanted on this arm (tag 29) was determined to be dead after implantation.

Fish were highly selective of the reservoir sections they used in 2007 and 2008 (X^2_{L2} = 118.77, P<0.0001 and X^2_{L2} = 116.50, P<0.0001, respectively). Selection ratios indicated that fish avoided the lower lake and selected for the upper Red River section in both 2007 and 2008 (Figure 11). Although selection ratios for the upper Washita were greater than 1 both years, selection could not be confirmed as the value of 1 was included in the 95% Bonferroni confidence intervals both years.

Home ranges of individual paddlefish were highly variable. Linear home ranges did not differ among seasons (F = 1.67, P = 0.181) or between years (F = 3.36, P = 0.1263; Figure 12). Most paddlefish had a home range that consisted of nearly the entire lake, whereas a few were confined to just a small portion of it. Paddlefish had annual linear home ranges from 5.97 to 61.44 km, with a mean size of 37.41 km. Fish occupied a mean depth of 7.27 m (range = 0.3 m to 21.1 m) throughout the year but were never found to inhabit depths with less than 3 mg/l dissolved oxygen.

Population Dynamics

In the winters of 2007 and 2008, a total of 262 paddlefish were collected and 221 were tagged with monel jaw tags. The fish not tagged included 15 mortalities, 14 recaptures, and 12 unmarked. Immediate mortality due to gillnetting was estimated to be 5.4% in 2008, and 6.1% in 2009, with an overall rate of 5.7%. The paddlefish population in Texoma was estimated at 1,346 (95% CIs: 701-4,925), and 1,761 (95% CIs: 869-8,610) fish in 2008 and 2009, respectively. The range of the confidence intervals for 2009 was larger because of a lower number of recaptures. Catch rates in the Red River arm of the lake were 3.64 and 3.24 fish/24 h set in 2007 and 2008, respectively. The Washita River arm had catch rates of 2.03 fish/24 h set in 2008 and 5.10 fish/24 h set in 2009. The high catch rate in the Washita River arm was influenced by limited samples and a high number of fish caught on the last sampling trip.

Paddlefish were in good condition with a mean (± SE) relative weight (R_w) of 129 ± 1.79 in 2008 and 118 ± 1.45 in 2009. It is common for paddlefish in lentic systems to be in better condition than those in lotic systems (Russell 1986). Paddlefish also exhibited rapid growth up through age-5 and substantially decreased growth there after (Table 3). The most growth shown in one year by a recaptured fish was 80 mm and 6.8 kg.

The oldest known paddlefish collected was eight years old, as determined by a previously implanted coded wire tag. Larger fish were captured, although ages of these fish were not determined, primarily because most were implanted with transmitters. Although the assumption of consistent recruitment was not met, because stocking rates ranged from 770 to 30,478 fish annually and no natural reproduction was detected, catchcurves have been used to determine year class strength and estimate annual mortality for paddlefish (Hoxmeier and DeVries 1997, Paukert 2001a). The 2005 year-class, the largest stocking of paddlefish, appeared weak in both the 2008 and 2009 catch data (Figure 13). This year class was also missing in the USFWS 2007 gillnetting survey. Annual mortality was estimated at 40.7% and 37.4% in 2008 and 2009, respectively.

Reproduction

Inflows from both the Red and Washita rivers during the spring of 2008 were above average (Figure 14). Although flows on the Red River are historically higher than the Washita River, the Washita River had higher flows in spring 2008 including three major peaks of inflow. The submersible receiver at the upper Red River site did not detect any tagged paddlefish during the spring. The two submersible receivers located at the mouths of each of the two rivers were not recovered. They were either covered with silt and sand, or washed downstream during the high flows. Three fish, all implanted on the Red River arm, were logged on the submersible receiver at the upper Washita River site. Fish 92 was logged on 10 March 2008 after a peak flow of 3,500 cfs. Fish 91 was logged on 26 March 2008 after a flow of 21,800 cfs. The other fish (tag 49) was not detected in the river until 4 May 2008 after a flow of 33,000 cfs. Water temperatures ranged from 9°C to 18°C during the time period paddlefish were found in the river.

Attempts to locate fish in the Washita River with the manual receiver and directional hydrophone were not effective due to movement of sand and water that severely reduced the detectable range of a transmitter. Electrofishing attempts in presumed spawning areas also proved unsuccessful, even though the submersible receivers documented that some paddle fish migrated up the Washita River during the spawning season.

CHAPTER V

DISCUSSION

Movements and Distribution

The movements and distribution of paddlefish in Lake Texoma were highly variable in 2007 and 2008, although most fish were in the upper ends of the reservoir. Locations recorded in the spring of 2007 were from the upper reservoir; however, during the major flood event in the summer of 2007, paddlefish dispersed widely throughout the lake with some tagged fish remaining in the upper ends while others moved downstream to the lower reaches of the reservoir. Their dispersal during this time was also shown by anglers that reported jaw tagged paddlefish being caught below the dam of Waurika Reservoir on the upper Red River. These paddlefish had traveled from Lake Texoma 250 km up the Red River into Beaver Creek below Waurika. As water levels returned to normal most paddlefish were once again located in the upper sections of the reservoir. In 2008, a normal water year, paddlefish were consistently found in the upper ends of the reservoir. Locations in the lower lake section were primarily observed when paddlefish moved from the upper section of one river arm to the other. Although other studies have documented seasonal migrations of paddlefish (Hagman et al. 1988, Paukert and Fisher 2000, Stancill et al. 2002), only a few fish in 2007 displayed a downstream migration after the spawning season in Lake Texoma.

Selection ratios indicated that fish preferred the upper Red River section of the lake. This was also evident in previous gill net surveys by the USFWS (Brent Bristow, USFWS, personal communication). Historically, Lake Texoma has been a highly-productive, phosphorus-limited reservoir with the greatest productivity coming from the upper part of the Red River arm. From 29 October 2007 to 29 July 2008, the mean total phosphorus for the upper Red River, upper Washita River, and lower lake sections were 0.72, 0.4, and .039 mg/L, respectively (Oklahoma Water Resources Board, unpublished data). It is possible that paddlefish are drawn to the upper Red River arm because its higher productivity has historically supported a higher abundance of zooplankton (Atkinson et al. 1999, Crist 1980).

Another possible factor influencing reservoir section selection by paddlefish is lake morphology. The upper arms of Lake Texoma are much narrower than the lower lake area, making it easier to cover while tracking paddlefish. Fish would more likely have been missed in the lower lake section, although this is not believed to have had an impact on the results as most fish were routinely found.

Paddlefish are known as a highly mobile species. Zigler et al. (2003) documented paddlefish traveling over 420 km in a year in the Mississippi River. Paddlefish in Lake Texoma also exhibited high mobility as one paddlefish traveled over 30.4 km in three days. The mean linear home range (37.41 km) for paddlefish suggests that they used a majority of the reservoir, considering that the minimum distance between the mouths of the two rivers is 62.01 km.

Population Dynamics

The population estimates in 2008 and 2009 were fairly consistent. The 2009 estimate showed a slight increase in the population, although a true increase is unlikely because of high mortality rates and the low number of paddlefish stocked in 2007 that would have recruited to the gear. These estimates had wide confidence intervals, as has been observed for other paddlefish populations (Ambler 1994, Paukert 1998, Gordon 2004,).

The size of the paddlefish population in Lake Texoma is low; approximately 1.5% of the fish that have been stocked over the last 10 years have survived. Annual mortality estimates obtained from Lake Texoma in 2008 and 2009 were approximately 40%, which is greater than most other paddlefish populations (26% to 48% in southern waters with little or no exploitation; Reed et al. 1992, Hoxmeier and DeVries 1997, Paukert and Fisher 2001a). This high mortality rate is likely due to a combination of emigration and mortality. Emigration of a few fish through Denison Dam has been confirmed by the USFWS when collecting paddlefish broodstock (Brent Bristow, personal communication). Both coded-wire-tagged fish and jaw-tagged fish from Lake Texoma have been collected below the dam in the Red River. The number of fish going over the dam has not been quantified, although the amount of emigration is assumed to be insignificant. Although paddlefish were grown $\geq$ 305 mm TL before being released to minimize predation, it has yet to be determined if predation or other natural conditions could have contributed to the high mortality rate observed in Lake Texoma.

The paddlefish captured were in good condition, which is consistent with two reintroduced populations (Kaw and Oolagah Reservoirs) and two natural populations (Keystone and Grand Reservoirs) in Oklahoma (Paukert 2001, USFWS unpublished data, ODWC unpublished data). The fish in Lake Texoma exhibited growth similar to these other Oklahoma populations (Figure 15). Growth through age four was higher for Lake Texoma fish but was lower thereafter, presumably because of the low number of fish collected that were older than age five. With the good body condition and high growth rate observed in the Lake Texoma population, it is assumed that resources are not a limiting factor for this population.

Reproduction

Paukert and Fisher (2001a) determined that river flow was the limiting factor for successful paddlefish reproduction in Keystone Reservoir, Oklahoma. This is likely to be the case for the Lake Texoma population. Female paddlefish would have first sexually matured in Lake Texoma in 2004 (based on other paddlefish populations in Oklahoma, which mature in 5-6 years; Paukert 1998, Brent Gordon, personal communication). From 2004 through 2006 there were no high inflows during spring, which would have limited paddlefish migration upstream to suitable the suitable spawning substrate. In 2007 there were two pulses of high inflow during the spring in both the Red and Washita rivers. Although conditions would have been more favorable for successful reproduction in 2007, we did not document any natural reproduction as the resulting progeny would have recruited to the gear in 2009.

River flows in 2008 were also likely to be conducive for successful reproduction. Firehammer and Scarnecchia (2006) determined paddlefish of the Yellowstone-Sakakawea stock ascended into the tributary river with highest flow and turbidity. The two main tributaries of Lake Texoma, the Red and Washita rivers, had similar inflow pulses although each pulse was higher in the Washita River during the spring of 2008. Three fish implanted with transmitters in the upper Red River arm migrated up the Washita River during the spring. Although fish were identified in the Washita River during the spring, no spawning activity was documented at presumed spawning locations.

Management Implications

The paddlefish population in Lake Texoma is on the periphery of the historic range for the species (Gengerke 1986). Presumably, Lake Texoma has the food and habitat resources to support a naturally reproducing population of paddlefish, but high inflows in the spring will be critical for the population to naturally sustain itself. Water flows are one of the three critical components for successful reproduction (Russell 1986), and Paukert and Fisher (2001b) found water flows to be the most important factor in a prairie-reservoir system. Annual surveys in Lake Texoma should be continued in the upper ends of the reservoir, particularly the Red River arm, to monitor the population for natural reproduction and recruitment. Natural reproduction was not detected in Kaw and Oolagah Reservoirs until approximately 10 years after initial stockings (B. Bristow, USFWS, personal communication).

Before additional paddlefish stockings are conducted, future research should focus on causes of mortality and should quantify emigration from the reservoir. With high total annual mortality and limited or no natural reproduction, it is unclear whether the population will be able to sustain itself. It is also unclear why paddlefish selected the upper section of the Red River over the upper Washita River or lower lake. The upper Red River arm of the lake has significantly higher salinity than the Washita River arm and main pool of the lake. Although Paukert and Fisher (2000) suggested paddlefish may avoid highly saline water in a tributary of Keystone Reservoir, the paddlefish population in Lake Texoma did not. Paddlefish are nonselective filter feeders and consume zooplankton species in proportion to their abundance (Russell 1986). It is possible that zooplankton densities may play a vital role in paddlefish distribution because paddlefish in Lake Texoma selected the area of the reservoir with the highest historical abundance of zooplankton (Atkinson et al. 1999, Crist 1980). Further research is warranted to determine if physical, chemical, or biological factors are affecting paddlefish distribution in the Lake Texoma system. A better understanding of the Lake Texoma paddlefish population will help ensure their survival and enable managers to adequately assess the status of this reintroduced population.

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Table 1. Number of fish and mean length (mm TL) of paddlefish stocked in Lake Texoma, Oklahoma from 1999 to 2007.

Year	Number	Mean Length
1999	5,974	305
2000	20,846	305
2001	770	305
2002	16,792	305
2003	4,421	305
2004	26,330	305
2005	30,478	305
2006	10,920	305
2007	2,029	457

Table 2. Tag date, number, length (mm), weight (kg), river arm capture location, and linear home range of paddlefish implanted with ultrasonic transmitters in winter of 2007 and 2008 in Lake Texoma. (* Notes fish that were never found and + notes confirmed mortality.)

	Tag Date	Fish Tag #	River Arm Collected	Length (mm)	Weight (kg)	Linear Range (km)
		3	Red	844	10.65	26.59
	1/24/2007	11	Red	885	13.60	61.44
	1/24/2007	24	Red	841	12.25	16.58
	1/24/2007	43	Red	826	10.10	31.60
	1/25/2007	2	Red	873	12.65	29.89
	1/25/2007	5	Red	1036	25.00	8.18
	1/25/2007	6	Red	886	13.25	43.86
	1/25/2007	8	Red	736	9.30	9.85
	1/25/2007	18	Red	820	11.20	50.44
	1/25/2007	22	Red	830	11.05	59.14
	1/25/2007	31	Red	875	12.30	31.90
	1/25/2007	34	Red	1024	21.80	59.87
	3/6/2007	13	Washita	1066	28.35	5.97
	3/6/2007	20	Washita	1038	22.25	41.08
	12/13/2007	81	Red	970	23.00	33.68
	1/3/2008	80	Washita	1009	21.50	60.09
+	1/3/2008	83	Washita	1050	22.00	——
	1/31/2008	49	Red	951	19.50	56.07
	1/31/2008	50	Red	1171	34.00	11.88
	1/31/2008	59	Red	1049	26.50	48.08
	1/31/2008	71	Red	986	22.00	59.07
	1/31/2008	78	Red	1016	22.50	22.18
*	2/1/2008	91	Red	964	26.00	——
	2/1/2008	92	Red	1040	31.00	7.83
	2/14/2008	101	Red	981	17.00	53.13
	2/21/2008	96	Washita	971	25.00	31.65
	2/22/2008	98	Red	908	21.00	46.08
*	3/6/2008	29	Red	972	25.00	——
	3/6/2008	95	Red	896	21.50	46.20
	3/6/2008	100	Red	872	15.00	57.76

Table 3. Mean length (mm EFL) at age of paddlefish in Lake Texoma, Oklahoma from 2008-2009 (standard error is in parentheses).

Age	Mean length (mm)		N
2	686	(4.3)	81
3	810	(6.2)	79
4	884	(10.3)	50
5	963	(12.2)	35
6	973	(18.7)	8
8	995		1

Figure 1. Diagram of the three sections of Lake Texoma, the Upper Red, Upper Washita, and Lower Lake. Locations of submersible receivers (SUR's) in both the Red and Washita rivers are also shown.

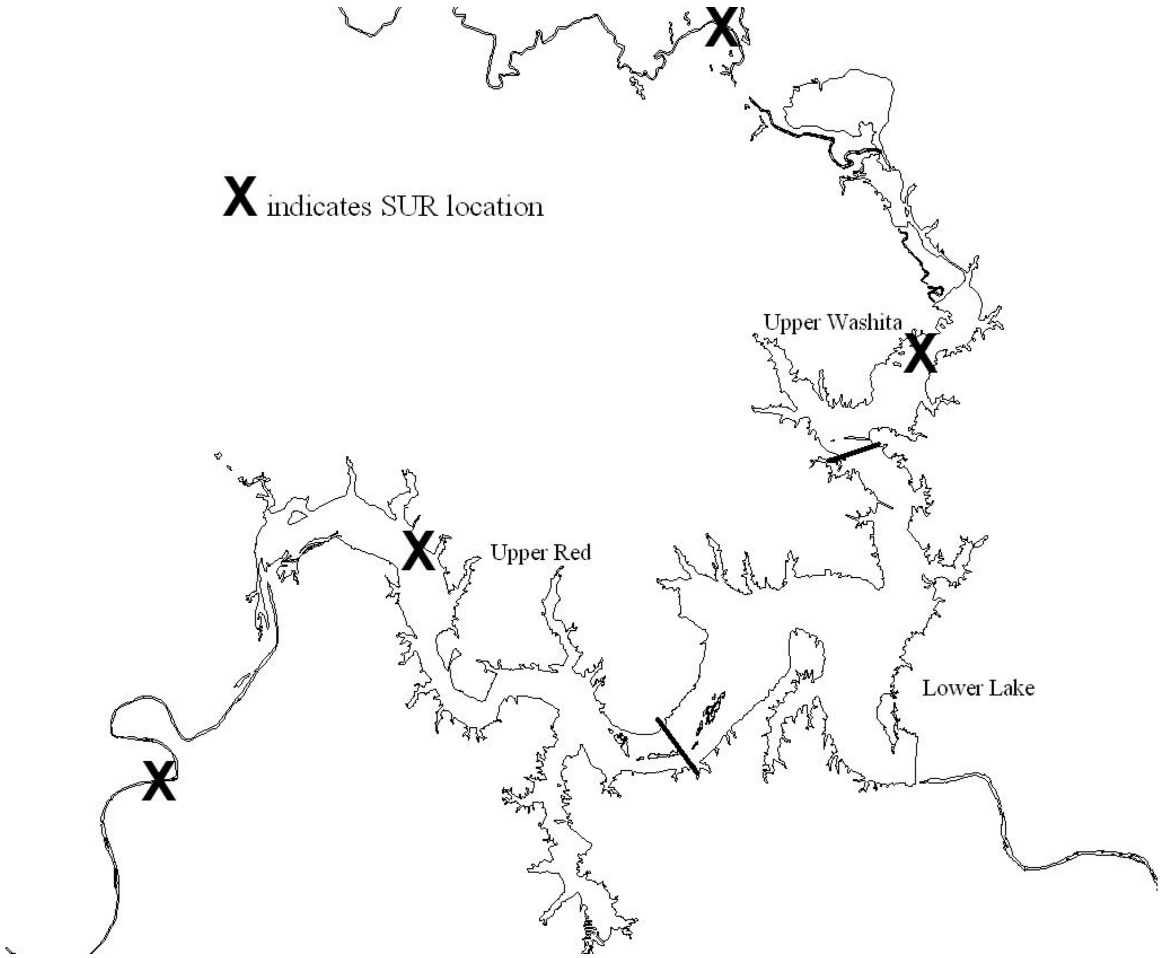


Figure 2. 289 locations documented from the spring of 2007 through the winter of 2008 in Lake Texoma, Oklahoma.

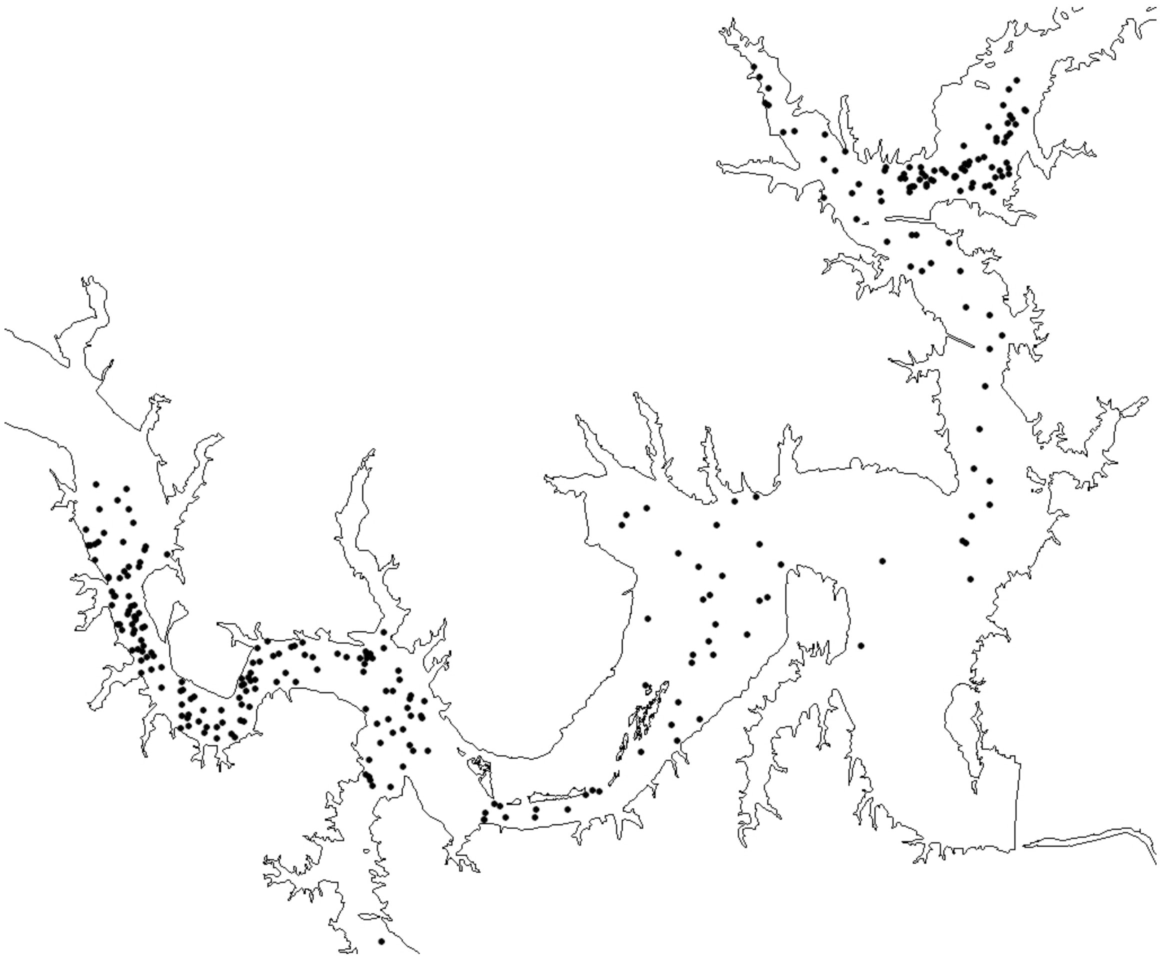


Figure 3. Pool elevation in feet for Lake Texoma in 2007. (Source: U. S. Army Corps of Engineers)

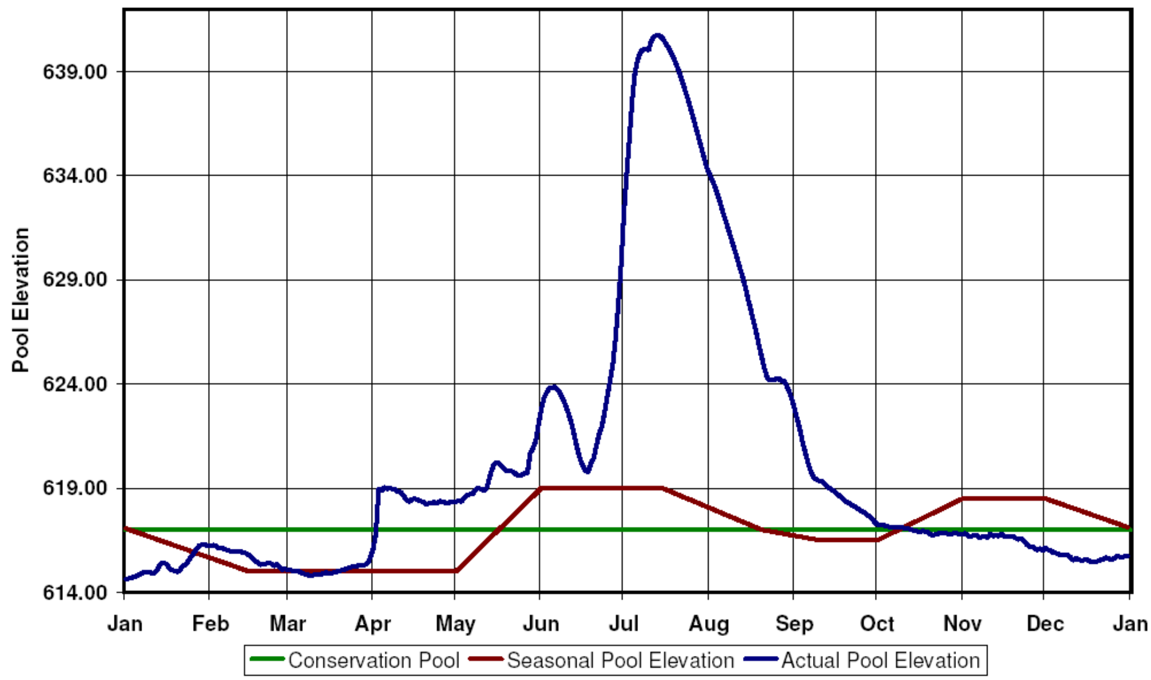


Figure 4. Locations for six fish that exhibited a downstream movement in the summer and fall of 2007. Locations are noted by: SP-spring, SU-summer, FA-fall, and WI-winter.

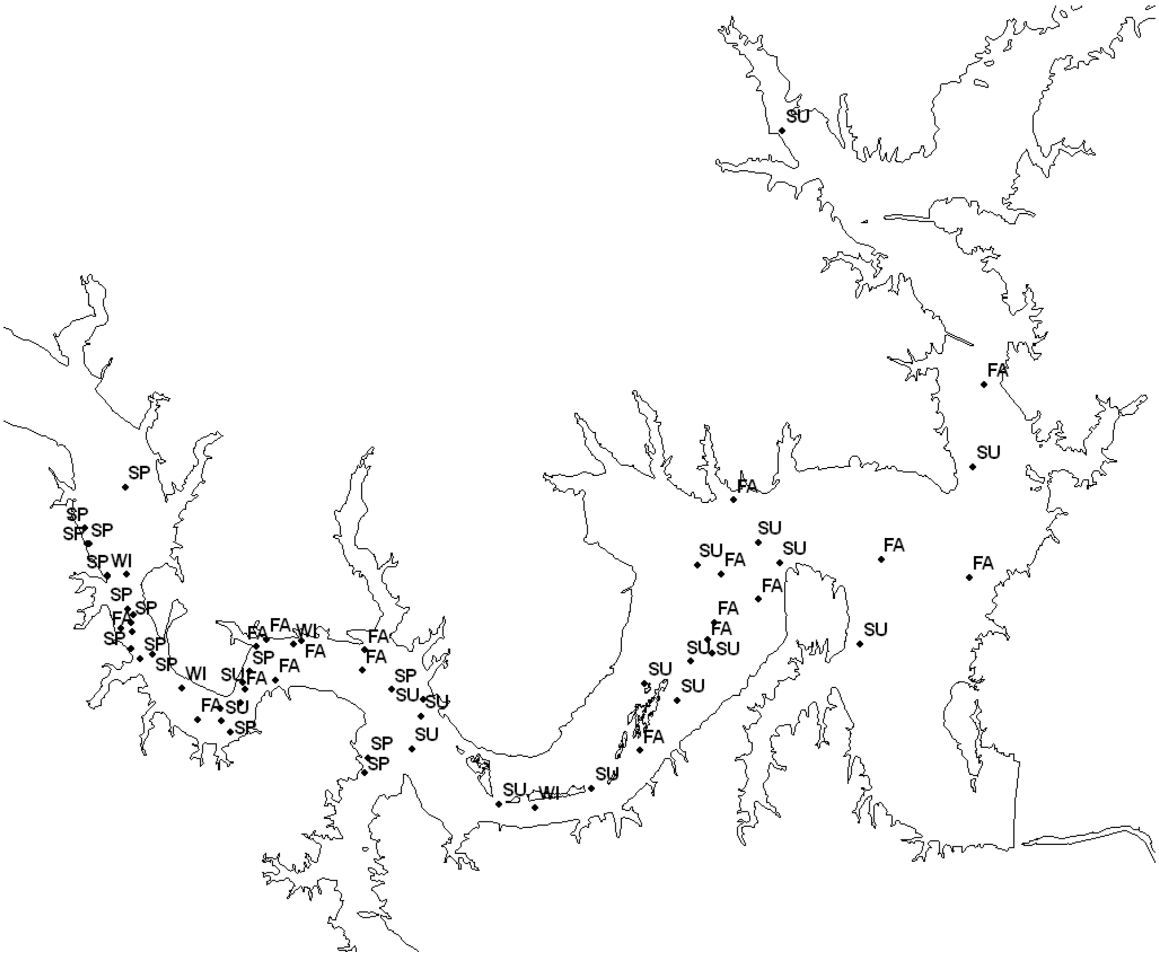


Figure 5. Locations for four fish that stayed mostly in the Upper Red section of Lake Texoma, Oklahoma in 2007. Locations are noted by tag number.

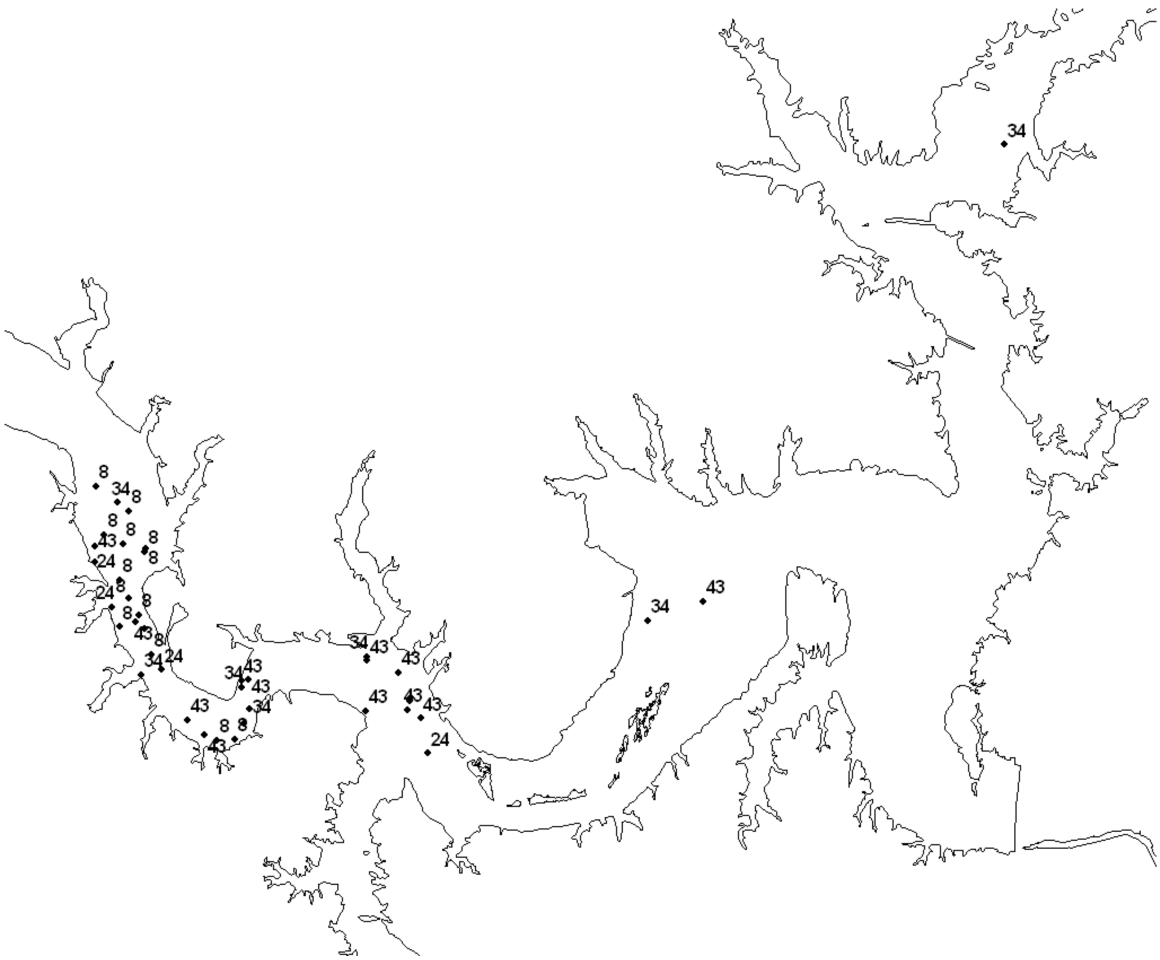


Figure 6. Locations for fish 11 and fish 5 which were tagged on the Upper Red arm of Lake Texoma. Locations are noted by season: SP-spring, FA-fall, and WI-winter.

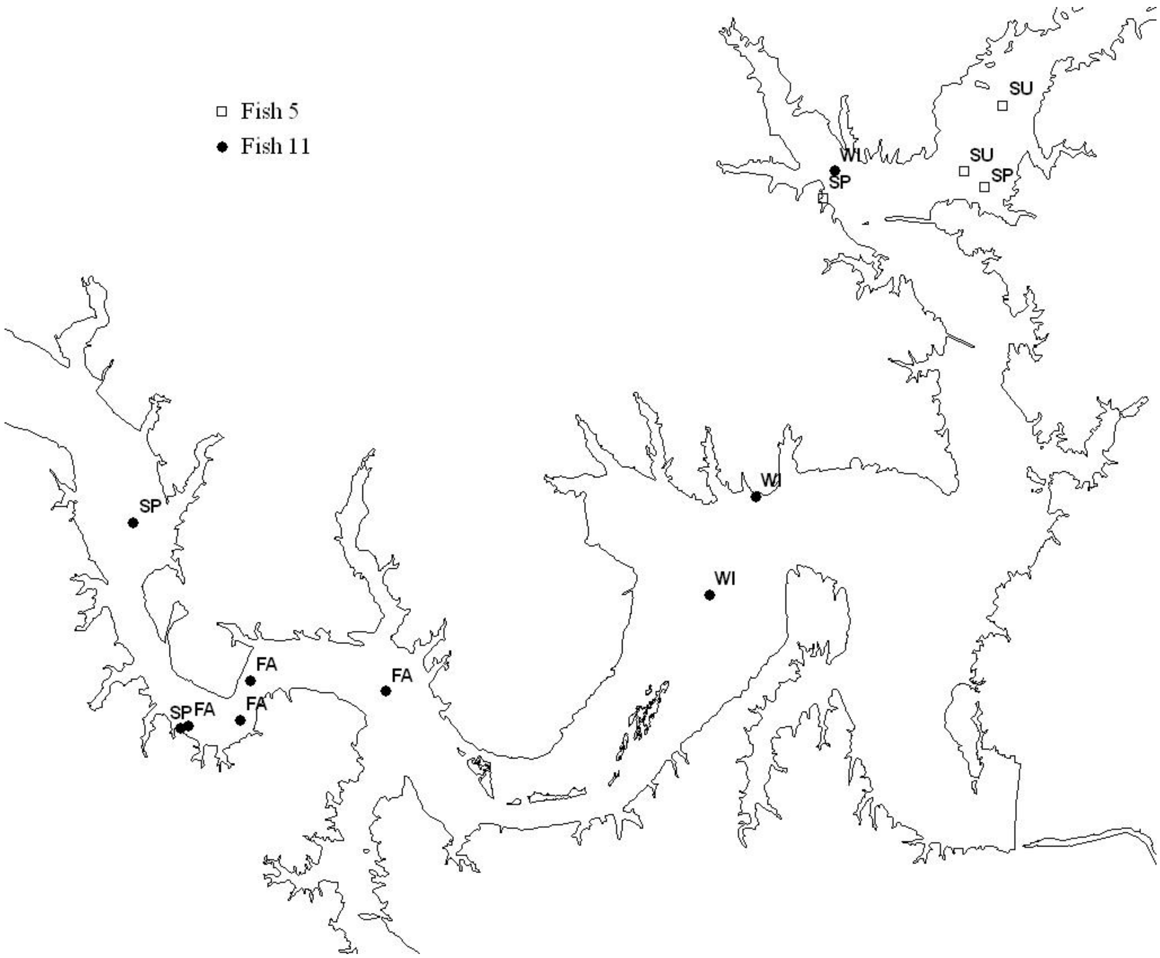


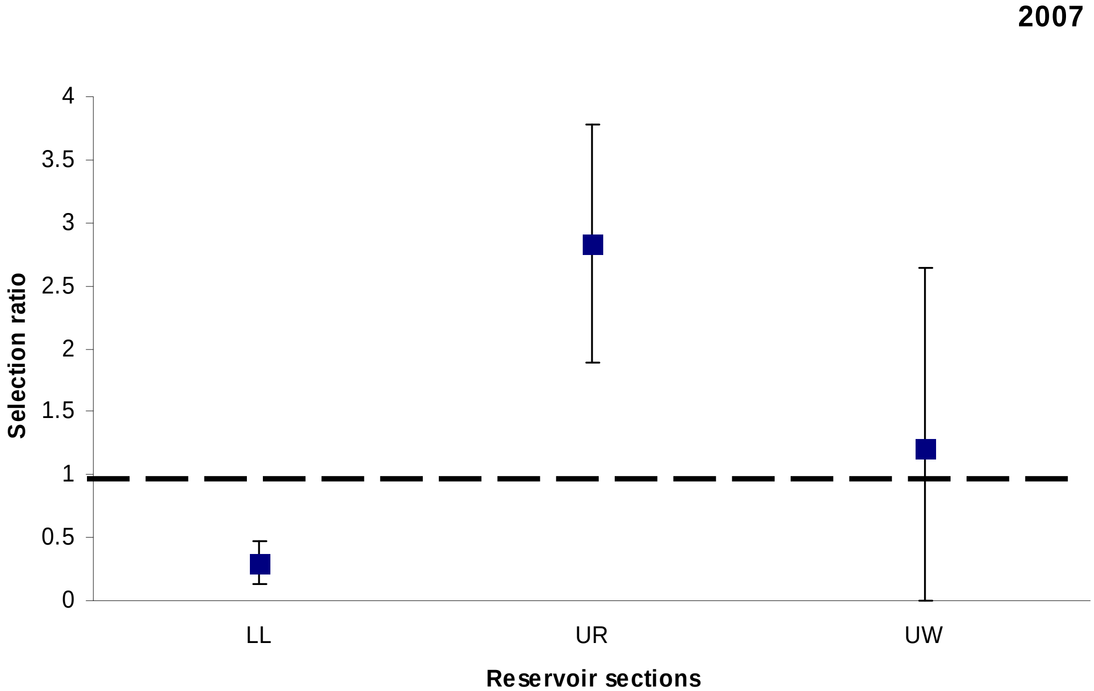
Figure 7. Locations for two fish implanted in 2007 on the Upper Washita section of Lake Texoma, Oklahoma. Locations are noted by tag number. Fish 20 traveled a minimum of 30.4 km in three days.

Figure 8. Locations for fish implanted on the Red River arm that inhabited both river arms of Lake Texoma, Oklahoma in 2008.

Figure 9. Locations for two fish that inhabited only the Red River arm of Lake Texoma, Oklahoma during 2008. Tag numbers are noted at each location.

Figure 10. Locations for the two fish tagged on the Upper Washita in 2008. Locations are noted by tag number.

Figure 11. Selection ratios and their 95% Bonferonni confidence intervals of the three sections of Lake Texoma, Oklahoma. Values (>1) indicate selection for while values (<1) indicate selection against.



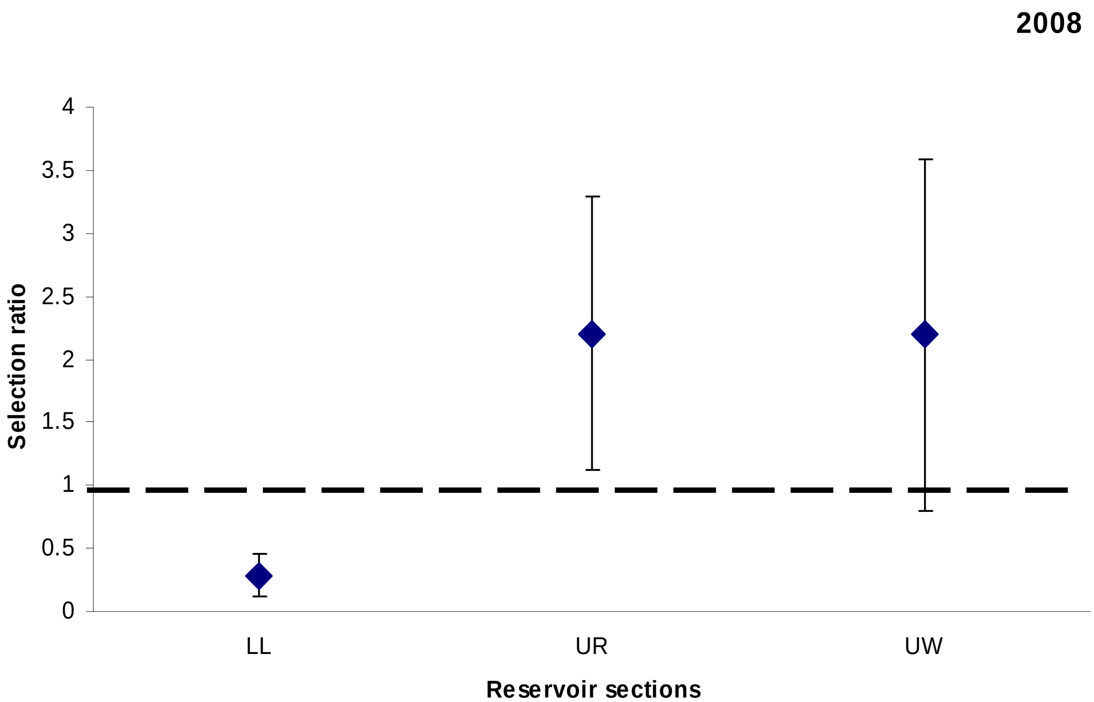


Figure 12. Mean linear home range and standard error of paddlefish in Lake Texoma, Oklahoma for each season in 2007 and 2008. There were no significant differences in seasons or years.

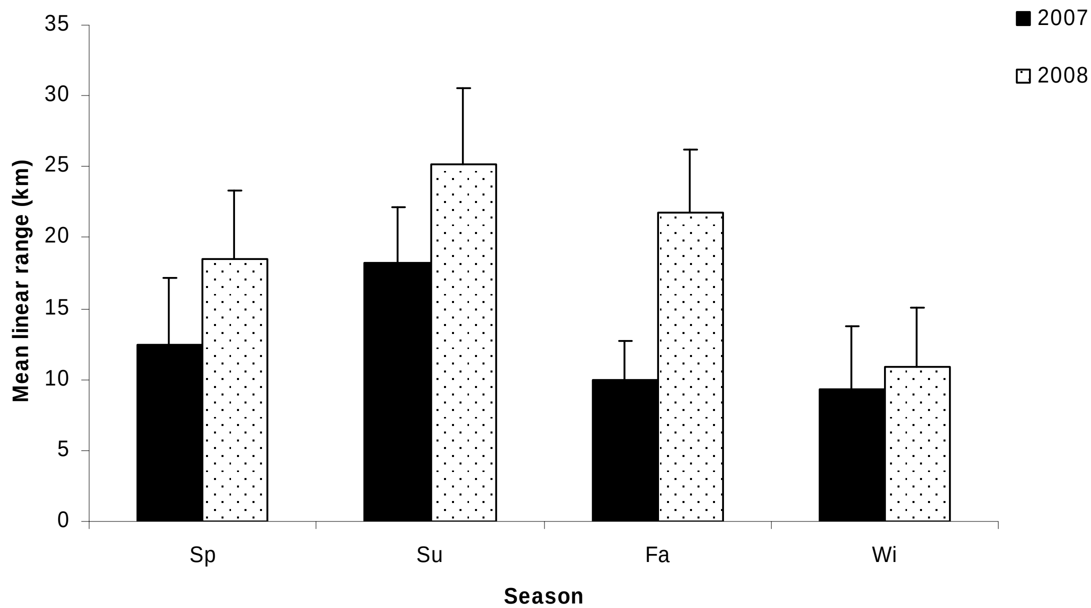
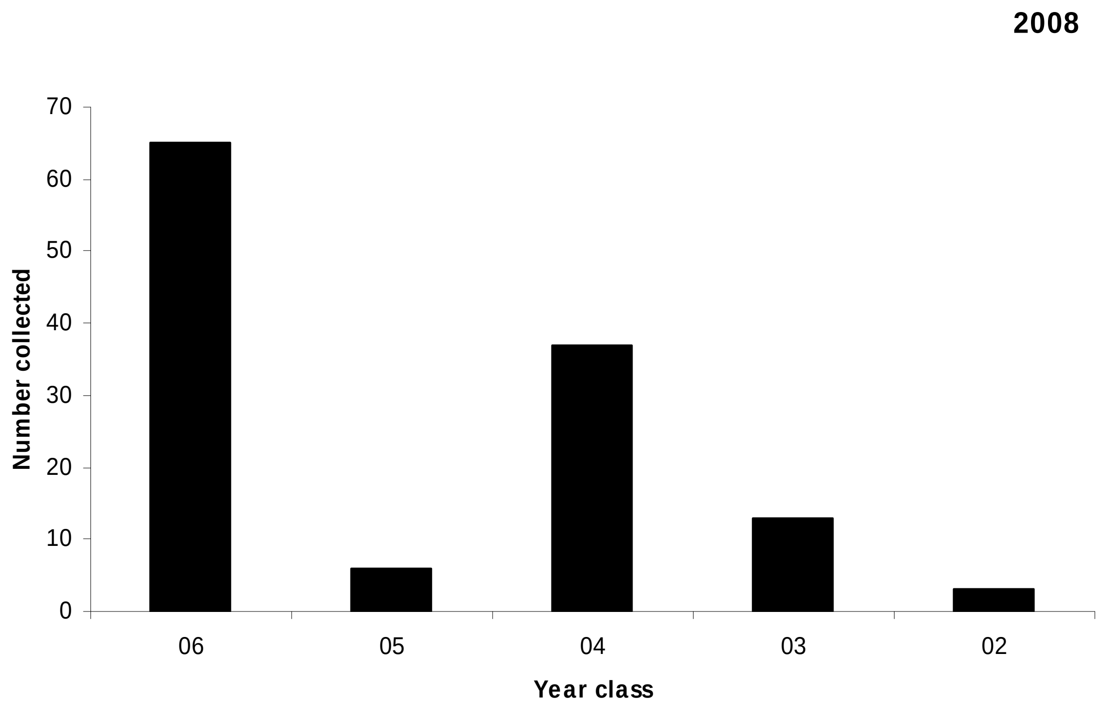


Figure 13. Catch curve of Paddlefish collected in 2008 and 2009 at Lake Texoma, Oklahoma.



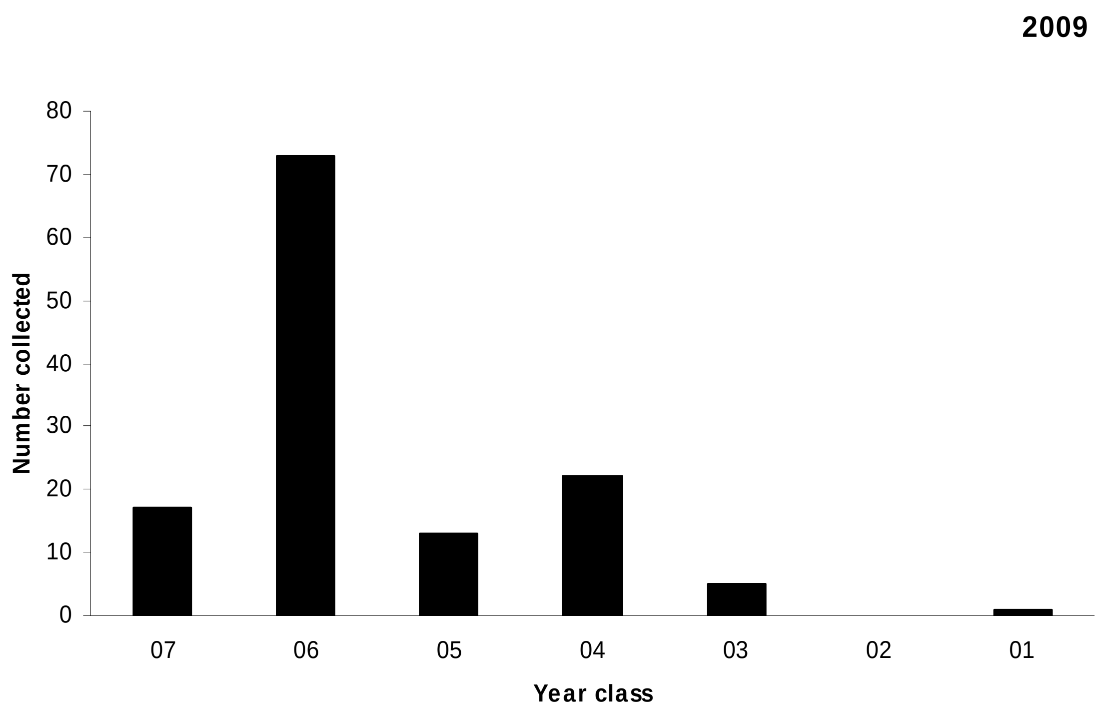


Figure 14. Daily mean discharge from the United States Geological Survey gauging stations in the Red River and Washita River above Lake Texoma, Oklahoma in the spring of 2008.

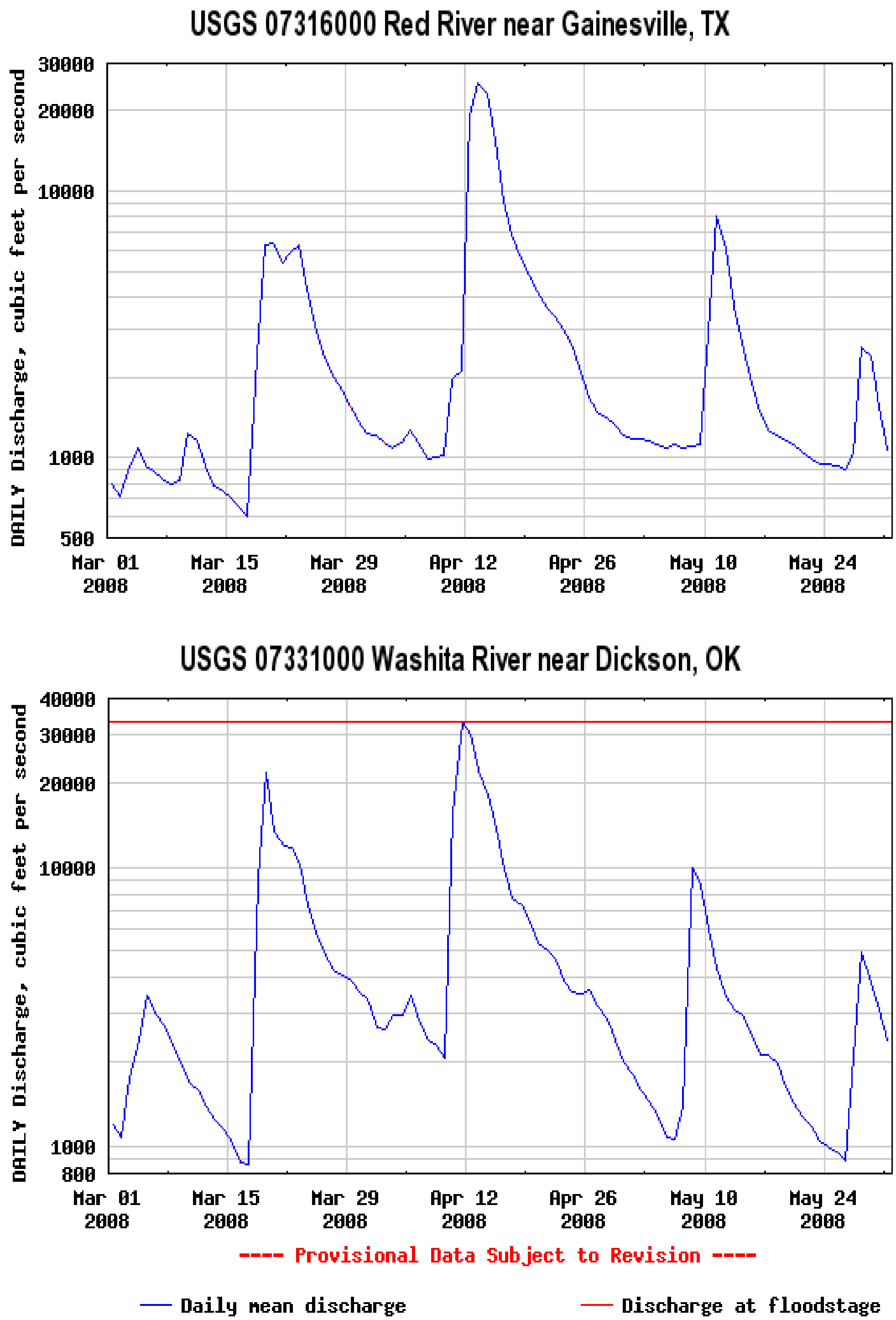
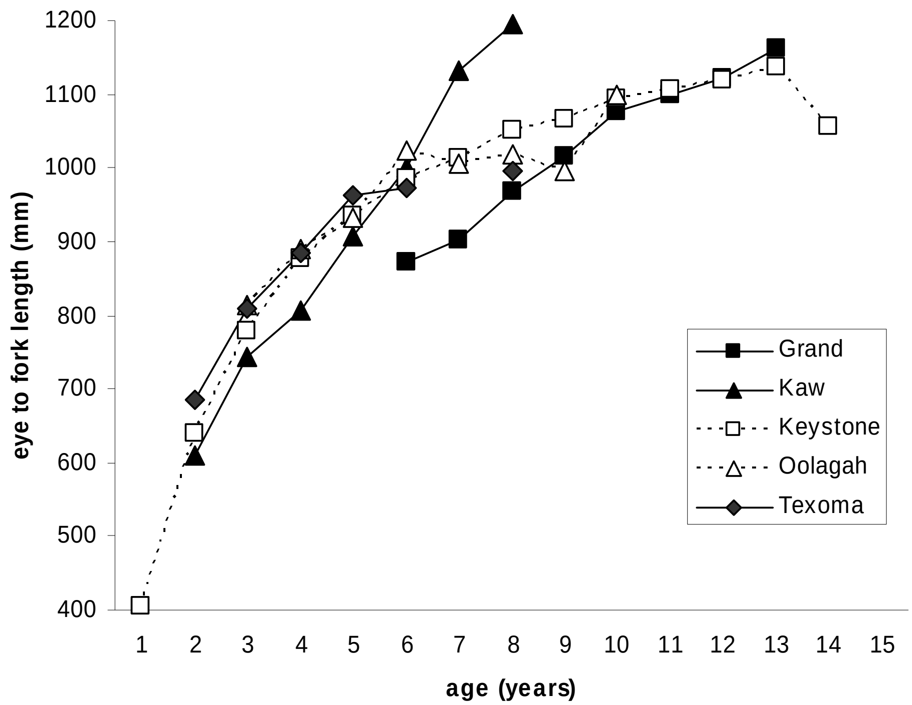


Figure 15. Mean length at age for three reintroduced populations of paddlefish and two natural populations in Oklahoma. Data from Lake Texoma, are from this study; Kaw Lake and Lake Oolagah from USFWS unpublished data; Keystone Reservoir from Paukert and Fisher (2001); and Grand Lake are from Combs (1982).



VITA

Chas Patrick Patterson

Candidate for the Degree of

Master of Science

Thesis: ECOLOGY OF A REINITRODUCED POPULATION OF PADDLEFISH, *POLYODON SPATHULA*, IN LAKE TEXOMA

Major Field: Natural Resource Ecology and Management

Biographical:

Education:

Watonga High School, Watonga, Oklahoma in 2000. Bachelor of Science in Zoology, University of Oklahoma, Norman, Oklahoma in 2005. Completed the requirements for the Master of Science in Natural Resource Ecology and Management at Oklahoma State University, Stillwater, Oklahoma in December, 2009.

Experience:

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Name: Chas P. Patterson Date of Degree: December, 2009

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: ECOLOGY OF A REINTRODUCED POPULATION OF PADDLEFISH, *POLYODON SPATHULA*, IN LAKE TEXOMA

Pages in Study: 47 Candidate for the Degree of Master of Science

Major Field: Natural Resource Ecology and Management

Scope and Method of Study:

A reintroduction of paddlefish in Lake Texoma began in 1999 but subsequent annual surveys showed this population below that produced from other similar reintroductions in Oklahoma. To determine the current status of this population, 30 paddlefish were implanted with ultrasonic transmitters in 2008 and 2009 to determine their distribution and movements in the lake. Log-likelihood chi square tests and selection ratios were used to determine which areas of the lake paddlefish selected for and against. Linear home range was also calculated for each season and analysis of variance (ANOVA) was used to determine differences in seasons. The main tributaries of the lake were also monitored during the spring of 2007 to document spawning migrations. In addition, a stratified random sampling design was used to collect paddlefish with gill nets to estimate total abundance by modified Schnabel mark-recapture methods. Population characteristics such as growth and mortality were also determined from the netting data.

Findings and Conclusions:

Paddlefish in Lake Texoma selected for the upper Red River arm and against the lower lake in both 2007 and 2008 as indicated by selection ratios. Linear home range was not different among seasons P=0.18 or between years P=0.13. Paddlefish had an annual mean linear home range of 37.41 km that ranged from 5.97 to 61.44 km. The paddlefish population was estimated at 1,346 (95% CIs: 701-4,925), and 1,761 (95% CIs: 869-8,610) fish in 2008 and 2009, respectively. Paddlefish exhibited growth similar to other Oklahoma populations although mortality estimates of approximately 40% are higher than most other unexploited populations. Paddlefish migrated up the Washita River during the spring of 2007, although no reproductive activity or verification of naturally produced fish was documented. The success of the Lake Texoma paddlefish population will be highly dependant on adequate inflow to support successful natural reproduction.

ADVISER'S APPROVAL: William L. Fisher