W 2800.7 F532r/w no. 16
3/2002-2/2006 c.1

FINAL REPORT

RESEARCH AND SURVEYS

FEDERAL AID GRANT NO. F-50-R

FISH RESEARCH FOR OKLAHOMA WATERS

PROJECT NO. 16

COMPARISON OF STRIPED BASS EGG PRODUCTION AND JUVENILE STRIPED BASS ABUNDANCE BETWEEN THE WASHITA AND RED RIVERS

MARCH 1, 2002 through FEBRUARY 28, 2006

FINAL REPORT

State: Oklahoma Grant Number: F-50-R

Grant Title: Fish Research for Oklahoma Waters

Project Number: 16

Project Title: Comparison of striped bass egg production and juvenile striped bass abundance between the Washita and Red Rivers

Project Period: March 1, 2002 - February 28, 2006

Project Objectives: 1) To determine if gellen balls can be used as surrogate striped bass eggs to perform mark and recapture estimates of striped bass egg production in the Red River and Washita River; 2) To compare juvenile striped bass and age-0 shad spp. abundance between the Red River arm and Washita River arm of Lake Texoma.

ABSTRACT

Striped bass recruitment in the Red River arm and Washita River arm of Lake Texoma was monitored using drift net sampling for eggs, along with seine and gill-net sampling for juveniles from 2001-2004. Spawning locations in both rivers varied by year and flow. Primary spawning sites on the Red River were between 60-69 km, 90-109 km, and 140-159 km upstream of the lake; Washita River spawning locations were between 70-89 km and 100-109 km upstream. Comparison of efficiency-corrected catch rates of striped bass eggs between rivers indicated that more striped bass eggs are produced in the Washita River than in the Red River. Low flows are more detrimental to striped bass egg production in the Red River than in the Washita River as evidenced by the 2003 data. This is likely due to morphological differences between rivers; the Red having a shallow,

braided channel while the Washita has a deeper, more channelized basin. Statistical comparison of egg numbers produced by river by year failed to detect differences less than 300% and consequently may not be a good measure of striped bass recruitment in Lake Texoma. No between-arm differences in juvenile striped bass abundance were noted statistically in the 2000-2002 samples. Seine catches in the Washita River arm were higher than in the Red River arm in 2003. Flows in the Red River arm never exceeded 800 cfs in 2003. Catches of striped bass were higher in the Red River arm in 2004. No among-year differences were found in seine catches of juvenile striped bass in the Washita River arm, 2000-2004. Among-year differences in seine catch in the Red River arm were evident with 2003 being the lowest and 2004 being the highest. Age-0 shad abundance, as measured by surface-set gill-net samples, was high and dominated by threadfin shad even following a partial winterkill in 2000-2001. No between-arm differences in age-0 shad abundance were seen in 2000, 2001, 2002, nor 2004. Catches of age-0 shad were higher in the Red River arm in 2003. No among-year differences were seen when catches of threadfin and gizzard shad were combined, 2001-2004. The relative between-arm differences in March gill-net samples mirrored the differences seen in the respective seine samples for the 2002 and 2003 year classes of striped bass. However, this relation did not hold for the 2004 year class. Samples sizes for the seine and March gill-net samples for age-0 striped bass need to be increased to reach a target precision of $CV_{\bar{x}}=0.20$.

I. Problem or Need

The striped bass *Morone saxatilis* fishery at Lake Texoma is estimated to provide $28 million in direct benefits to the local economy annually (Ditton and Hunt 1996; Hunt and Ditton 1998). As such, this fishery is the single-most economically valuable fishery resource in the state. Recently, the status of the striped bass fishery has been threatened by proposed water development projects in the upper Red River watershed (Red River Authority of Texas 1997). The project has the potential to reduce flows in the Red River and alter the water quality of Lake Texoma. These changes could have significant impacts on striped bass recruitment and alter the predator-prey balance in Lake Texoma.

Striped bass spawn in both the Red River and Washita River (Mauck 1983). However, we do not know what proportion of striped bass production can be attributed to each river system. Density-independent factors, strongly influenced by the environment, control recruitment of striped bass (Rutherford and Houde 1975; Ulanowicz and Polgar 1980; Uphoff 1989). Transport of striped bass eggs depends on stream flow (Johnson and Koo 1975; Bulak et al. 1993) and developmental temperature (Calhoun et al. 1950; Kornegay and Humphries 1976; Dudley and Black 1979). The combination of flow rates and water temperature are critical in ensuring that larval striped bass reach high quality nursery habitat in the upper reaches of reservoirs (Bulak et al. 1997; Chick and Van Den Avyle 1999). Given the potential for alteration of flow regime through the water development projects and the recruitment biology of striped bass, several questions come to mind; 1) if flows in the Red River are significantly reduced, will striped bass production be negatively impacted and, if so, 2) is production from the Washita River

sufficient to maintain the fishery in its current state? If production from the Washita River is sufficient to support the fishery, then water quality issues would be the only argument to stop further construction of water retention structures on the Red River. However, if production from the Red River is vital to sustaining the striped bass fishery, then arguments against further construction could be significantly enhanced.

II. Background

Striped bass spawn in both the Red River and Washita River (Mauck 1983). However, we do not know what proportion of striped bass production can be attributed to each river system. Striped bass eggs were collected from both the Washita and Red Rivers in spring 2001 (Boxrucker 2003). Estimates indicated that the number of eggs/m^3 collected in the Washita River was greater than that in the Red River. However, channel morphology differs greatly between the two systems. The Washita River channel is well defined which restricts flow to a limited area making sampling for eggs more efficient. The Red River is wider and has a braided channel which causes the flow to be spread out over a much larger area, resulting in reduced sampling efficiency on the Red River. Using a surrogate egg (gellen balls, hereafter referred to as gelatin beads) as a marker and performing a mark and recapture estimate would give a more accurate estimate of relative egg production between the two rivers than a catch-per-effort estimate.

Historical sampling of striped bass eggs in rivers has focused on determining spawning sites by taking into account the stage of development at time of collection and moving upstream based on flow rates obtained from United States Geological Survey (USGS) gauging stations. This method does not take into account variations in flow

across the river channel nor has historical sampling been able to estimate numbers of eggs produced. Recent work on the Savannah River in Georgia (Reinert et al. 2004) utilized egg surrogates (gelatin beads) as a marked sub-sample which facilitated making a population estimate of number of eggs moving down the river based on the proportion of marked eggs (gelatin beads) to striped bass eggs collected in the samples. Use of gelatin beads will allow estimation of capture efficiency among sites within each river and comparison between rivers at various flow rates. By using gelatin beads, researchers will also be able to test the validity of the historical estimates based on flow rates. Introducing marked eggs at a given point and collection of these eggs at some location downstream will facilitate comparisons of actual movement rates downstream to estimates of movement rates based on stage of development and flow rates from gauging stations.

This report will be broken into two parts. The first section deals with seine sampling for juvenile striped bass, gill-net sampling for gizzard shad *Dorosoma cepedianum* and threadfin shad *D. petenense*, and gill-net sampling for overwinter survival of age-0 striped bass. An attached addendum contains the egg-netting data and surrogate egg trials. This information is contained in Robert G. Ryan's Master's Thesis for the University of Oklahoma.

B. Methods:

Precision of gill-net estimates of age-0 shad abundance in Lake Texoma in 2001 (Boxrucker 2003) were higher than historical estimates with trawls or hydroacoustics (Summers et al. 2003). Consequently, the decision was made to eliminate trawl and hydroacoustic sampling from the project design. All estimates of shad recruitment were

made using surface-set gill nets.

Seine

Twenty fixed sites each on the Red River arm and the Washita River arm were sampled after dusk in June 2002-2004 with a 12.2 m bag seine of 6-mm Ace mesh (Figure 1). Sandy beach habitat was sampled. The project documents called for 40 sites/arm. Sampling under F-50-R, Project 14 (Boxrucker 2003) indicated that July seine samples may be biased toward smaller members of the cohort given that some individuals were >100 mm total length. Concerns were raised over this size fish being able to escape capture by the seine. Consequently sampling in this project was moved to late June. However, age-0 striped bass had not moved down to the lower parts of the lake by the end of June, limiting the amount of appropriate sampling sites in the Washita arm. The decision was made to limit the sites to 20/arm and do replicate hauls at each site on consecutive nights, still yielding the requisite 40 hauls/arm. A quadrant haul was made at each site with 117 m^2 of area sampled/haul. Each site was sampled on consecutive nights for a total of 40 hauls in each arm. Catches for a given site from consecutive nights' samples were averaged and a single estimate/per site was obtained. All age-0 striped bass were preserved on ice, counted and measured (total length) in the laboratory. Seine data from 2000 (F-50-R, Project 13) and 2001 (F-50-R, Project 14) were also included in the analysis. However, data from these projects were collected in late July.

Catch rates (number/haul) for each arm of the reservoir (Red River and Washita) and for arms combined were tested for normality using a Shapiro-Wilk Normality Test ($\propto \leq 0.05$). The distribution of catch rates was not normally distributed. Log_e-transformation

normalized the data from 10 of 15 samples. Consequently, differences in $\log_e$-transformed (number/haul +1) catches between arms were tested by year using a one-way ANOVA ($\propto \leq 0.05$). In addition, differences in median number/haul between arms by year were compared using a non-parametric Wilcoxon Rank Sum Test ($\propto \leq 0.05$). Catches of age-0 striped bass for arms combined were compared among years using a one-way ANOVA ($\propto \leq 0.05$) with $\log_e$-transformed data (number/haul +1). If differences among years were observed, Tukey's test ($\propto \leq 0.05$) was used to determine which years differed. Among-year differences in median number/haul were also compared using a Kruskal-Wallis nonparametric one-way ANOVA ($\propto \leq 0.05$). Precision of the mean catch estimates was expressed using coefficient of variation of the mean ($CV_{\bar{x}}$; Cyr et al. 1992). A target level of precision of $CV_{\bar{x}}=0.20$ was desired.

Daily mean stream flow measurements were obtained from the U.S. Geological Survey's website (http://nwis.waterdata.usgs.gov/nwis/discharge) for sites on the Red River (Gainesville, TX) and on the Washita River (Dickson, OK). Data were obtained for the dates 07 April through 10 May 2000-2004. These dates were inclusive of times striped bass eggs were found in the egg-netting samples (see Addendum this report; Ryan 2004).

Gill Net

Age-0 shad were collected in September 2001-2004 using surface-set gill nets comprised of four 7.6-m long by 1.6 m deep panels of 9.5 mm, 12.7 mm, 15.9 mm, and 19.1 mm mesh. Twenty fixed sites were sampled on each the Red River arm and Washita River arm (Figure 1). Original sites were selected randomly from 0.5 km^2 quadrants along the shoreline and sites fixed thereafter. Openwater sets were avoided in

efforts to reduce interaction with boat traffic. Nets were set in the evening and run the following day. Total hours that each net was fished were recorded. All shad in the net were sorted by mesh size and species. Total lengths were taken on 25 individuals of each species by mesh size. Counts were made of the remaining individuals by species. Lengths were assigned to individuals not measured based on the length distribution of the measured individuals. Catch/effort was determined by multiplying number/hour by 24 and expressed as catch/net-night.

Catch rate data were separated by species (shad spp. combined, gizzard shad, and threadfin shad). The data were tested for normality using the Shapiro-Wilk Test ($\propto \leq 0.05$). The data were not normally distributed. However, $\log_e$-transformation normalized data from 18 of 24 samples. Consequently, differences in catches between the Red River arm and the Washita River arm were tested using one-way ANOVA of $\log_n$CPUE+1 ($\propto \leq 0.05$). However, $\log_e$-transformation of the annual catch data by arms combined normalized only five of 12 samples. Consequently, differences in annual catch data by species combined, gizzard shad and threadfin shad were tested using a Kruskal-Wallis nonparametric one-way ANOVA ($\propto \leq 0.05$). Precision of the mean catch estimates was expressed using coefficient of variation of the mean with a target of $CV\bar{x}=0.20$.

Gill-net samples for age-0 striped bass were collected in March 2003-2005 using bottom-set nets comprised of four 15.4-m long by 1.6 m deep panels of 12.7 mm, 15.9 mm, 19.1 mm, and 25.4 mm mesh. Twenty fixed sites were sampled annually on the Red River arm and on the Washita River arm (Figure 1). All age-0 striped bass were counted and measured. Catch/effort was determined by multiplying number/hour by 24 and expressed as catch/net-night.

The data were tested for normality using the Shapiro-Wilk Test ($\propto \leq 0.05$). The data were not normally distributed and $\log_e$-transformation normalized data from only five of 18 samples. Consequently, differences in catches of age-0 striped bass between the Red River arm and the Washita River arm were tested using a non-parametric Wilcoxon Rank Sum Test ($\propto \leq 0.05$). Target level of precision of the mean catch estimates was $CV_{\bar{x}}=0.20$.

C. Results and Discussion

Seine

Seines are the preferred method of sampling juvenile striped bass for recruitment estimates (Minikkinen et al. 1995; Collins et al. 2003; Nemerson and Able 2003; Shepherd et al. 2004). The variability in the Texoma seine samples was high with number/site ranging from 0 to 665 (Table 1). Precision of the catch estimates ($CV_{\bar{x}}$) exceeded the target value (0.20) for 18 of 25 samples (Tables 1 and 2). Sample sizes will need to be increased to improve the precision estimates for future studies.

The mean and median number of age-0 striped bass collected in 2000-2002 seine samples from the Red River arm and the Washita River arm were not significantly different (Table 1). Median catches from the Red River arm were significantly less than those from the Washita River arm in 2003 (Wilcoxon Rank Sum Test; $P = 0.0064$; Table 1) with median number/haul being higher in the Red River arm than in the Washita River arm in 2004 (Wilcoxon Rank Sum Test; $P = 0.0000$; Table 1). Differences in mean number/haul showed the same pattern with catches in the Washita River arm being higher in 2003 (one-way ANOVA; $P=0.003$) and higher in the Red River arm in 2004 (one-way ANOVA;

P=0.0000).

The pattern of differences in seine catches between arms follows the same pattern observed in the efficiency-corrected egg netting samples for 2001-2003 (See Addendum Table 8; Ryan 2004). No differences in the efficiency-corrected egg catches were found between rivers in 2001 and 2002. However, egg catches in the Washita River in 2003 were significantly higher than the respective catches from the Red River. However, seine catches were higher in the Red River arm than in the Washita River arm in 2004 (Table 1) but no differences were seen in the efficiency-corrected egg catches between rivers in 2004 (See Addendum Table 8; Ryan 2004).

No differences in mean catch rates of age-0 striped bass (2000-2004) were found in the Washita River arm (one-way ANOVA; $P = 0.54$; Table 2) nor in the median catch rates (Kruskal-Wallis non-parametric one-way ANOVA; $P = 0.78$; Table 2). Among-year differences in mean seine catches were observed in the Red River arm (one-way ANOVA; $P \leq 0.0000$; Table 2) and in median seine catches (Kruskal-Wallis non-parametric one-way ANOVA; $P = 0.0000$; Table 2). Highest mean catches were seen in the Red River samples in 2004 (221.0/haul; Tukey's test; $P \leq 0.05$; Table 2) and lowest in 2003 (2.9/haul; Tukey's test; $P \leq 0.05$; Table 2). No differences in mean catches were seen between the 2000 and 2001 samples, nor between the 2001 and 2002 samples (Tukey's test; $P \leq 0.05$; Table 2). Among year differences in the data from both arms combined were detected using both mean and median catches (Table 2). Mean catches in 2000 and 2003 were similar and the lowest recorded during the study, 27.7/haul and 27.5/haul, respectively (Table 2). Mean catch in 2004 was the highest (127.5/haul) but was not significantly different from the mean catch in 2002 (54.7/haul; Table 2).

Differences in median catch rates showed similar patterns to mean catches, with a few exceptions. No differences were found in median catches from 2000-2002 (Table 2). Median catches in 2000 and 2003 were similar and the lowest recorded during the study. Median catch in 2004 was the highest recorded and yet not significantly different than the median catch in 2002 (Table 2).

Similar within-arm, among-year patterns were seen in the efficiency-corrected egg-netting samples. No among-year differences were seen in the Washita River samples (See Addendum Table 9; Ryan 2004). However, the seine samples detected more among-year differences in the Red River arm than did the egg-netting samples. No significant difference in median number of eggs captured in the Red River were found among the 2001, 2002, and 2004 samples (See Addendum Table 9; Ryan 2004). The 2003 egg numbers were different that the 2001 and 2004 samples but the same as the 2002 collections. The number of eggs collected in the Red River was lowest in 2003 (See Addendum Table 9; Ryan 2004); the same was observed in the Red River seine samples (Table 2). The among-year trends in mean and median catches from the Red River arm in the seine samples were similar (2004>2002>2001>2000>2003; Table 2). The among-year trends in mean and median egg-net catches from the Red River were not consistent (See Addendum Table 9; Ryan 2004).

Spring inflows from both the Red and Washita rivers in 2003 were the lowest of the 5 years presented (Figures 2 and 3). Peak flows in the Red River in 2003 were 800 cubic feet/sec (cfs; Figure 2). Peak flows in the remaining years in the study were a minimum of 10 times that value (Figure 2). Although peak flows in the Washita River were also lowest in 2003 (1300 cfs), the 2003 value was not as different as flows in the

other years on the Washita River as on the Red River. The low flows in the Red River in 2003 likely led to the lowest estimates in egg production (See Addendum Table 9; Ryan 2004) in the Red River arm of Texoma and seine catches (Table 2). Along with photoperiod (Crance 1985) and temperature (Hardy 1978), flows are key to stimulating striped bass spawning runs (Kornegay and Humphries 1976; Combs 1980). Flows needed for successful spawning reported in the literature were generally higher than those measured in this study. Flows on the Roanoke River, North Carolina were increasingly conducive to striped bass spawning as sustained minimum flows exceeded 5500 cfs (Fish and McCoy 1959). Flows ranging from 9000 to 290,000 cfs were conducive to successful spawning in the Apalachicola River, Florida (Crance 1985). Baker (2003) and Ryan (2004; see Addendum this report) reported that peaks in egg production on the Red and Washita rivers followed peaks in stream flow by 2-4 days. Flow in the Washita River during the 2003 spawning season peaked at 1300 cfs (Figure 3) but no difference in egg production among years with much higher flows was detected.

The size distributions of juvenile striped bass from the seine samples from the Red River arm and the Washita River arm are given in Figures 4 and 5, respectively. Mean length of the seine samples from the Red River arm ranged from 48.8 mm in 2004 to 63.7 mm in 2003 (Figure 4). The mean lengths of striped bass in the seine samples from the Washita River arm ranged from 45.5 mm in 2003 to 64.1 mm in 2004 (Figure 5). These results coupled with data from future research will be used to determine if a correlation between size and abundance of juvenile striped bass in the seine samples exists.

Gill Nets

Catches of age-0 shad in September gill-net samples were high and dominated by threadfin shad (Table 3). Samples of age-0 shad (species combined) from the Red River arm and Washita River arm averaged 830.6 and 727.8 shad/net-night, respectively in 2001. These catches were not statistically different (one-way ANOVA, P=0.17; Table 3). The respective catches of age-0 shad from each arm of the reservoir in 2002 averaged 874.8 and 1092.5 but were not significantly different (one-way ANOVA; P=0.25; Table 3). Catches of age-0 shad from the Red River arm were higher than those from the Washita River arm in 2003, 941.0 and 695.5, respectively (one-way ANOVA; P=0.02; Table 3). No between-arm difference in shad abundance was seen in 2004; catches in the Red River and Washita River arms averaged 1037.0 and 998.4, respectively (one-way ANOVA; P=0.57; Table 3).

Catches of threadfin shad from the Red River arm and Washita River arm in 2001 averaged 529.1 and 671.0/net-night, respectively (Table 3). These catches were not statistically different (one-way ANOVA, P=0.90). No differences were seen in catches of threadfin shad between arms in 2002 (one-way ANOVA, P=0.60; Table 3), 2003 (one-way ANOVA; P=0.11; Table 3), nor 2004 (one-way ANOVA; P=0.81; Table 3).

Differences in between-arm catches of gizzard shad were more evident. Catches of gizzard shad were higher in the Red River arm than in the Washita River arm in 2001, 301.5 and 56.8/net-night, respectively (one-way ANOVA, P = 0.0000), 2003, 138.9 and 21.0, respectively (one-way ANOVA, P=0.0008; Table 3), and 2004, 210.8 and 78.6, respectively (one-way ANOVA; P=0.002; Table 3). Gizzard shad catches in the Washita River arm exceeded those in the Red River arm in 2002, 144.8 and 70.3, respectively.

The difference was not significant, although nearly so (one-way ANOVA; P=0.06; Table 3).

No differences in median catch rates of shad species combined and arms combined in 2001, 2002, 2003, and 2004 were evident, 646.7, 763.9, 737.3, and 984.0, respectively (Krushal-Wallis nonparametric ANOVA; $P \leq 0.05$; Table 4). However, median catch of age-0 shad in 2001 was different that the respective catch in 2004 at the P=0.09 level. No among-year differences in median catch of age-0 gizzard shad were evident in 2001 (78.8), 2002 (72.7), and 2004 (107.9) (Krushal-Wallis nonparametric ANOVA; $P \leq 0.05$; Table 4). However, median catch of gizzard shad in 2003 (28.8) was different than the respective catch in 2001 and 2004 (Krushal-Wallis nonparametric ANOVA, $P \leq 0.05$; Table 4). Among- year differences in median catch of age-0 threadfin shad were evident between 2001 (563.9) and 2004 (809.9) only (Krushal-Wallis nonparametric ANOVA, $P \leq 0.05$; Table 4).

The gill-net data illustrate how the Lake Texoma clupeid forage population is dominated by threadfin shad in the absence of recent winterkills. A winterkill occurred during the 2000-2001 winter (Paul Mauck, pers. comm.). No evidence of an increase in gizzard shad abundance was seen immediately after the winterkill (2001, Table 4). However, numbers of threadfin shad remained similar for three years following the winterkill (2001-2003; Table 4) but increased significantly the fourth year (2004; 809.9; Table 4) following the winterkill (2001; 563.9; Table 4).

Between-arm differences in median catch rates of age-0 striped bass in March gill-net samples were evident for the 2003 year class only, 1.2/net-night in the Red River arm and 14.2/net-night in the Washita River arm (Wilcoxon Rank Sum test, P=0.0000;

Table 5). The seine samples in 2003 also indicated a higher age-0 striped bass abundance in the Washita River arm (Table 1). However, the seine samples also detected a significant difference between arms in the 2004 samples (Table 1) which was not evident in the March 2005 gill-net samples (Table 5). The pattern in between-arm differences in the seine and gill-net samples was similar for the 2002 and 2003 year classes (Figure 6). This suggests that year-class strength may be fixed by June and that seining in early summer and gill netting in late winter are comparable methods for evaluating year-class strength. However, the pattern broke down for the 2004 year class. Additional sampling under F-50-R, Project 20 should help clarify these relations.

The within-arm, among-year differences in abundance of age-0 striped bass from the seine and gill-net samples were similar for the Red River arm (Tables 2 and 6). Median catches of the 2003 year class for both gears were less than the respective catches for the 2002 and 2004 year classes (Tables 2 and 6). Median gill-net catch of the 2002 year class in the Washita River arm was less than the respective catches of the 2003 and 2004 year classes (Table 6). No among-year differences in median nor mean seine catches of age-0 striped bass were seen in the Washita River arm (Table 2). Between-arm movements of age-0 striped bass between the time of seine and gill-net sampling may account for these discrepancies. However, when data from both arms were combined, the pattern of among year differences in median abundance was not the same for the seine and gill-net samples. Year-class strength, as measured by the gill-net samples, were similar for the 2002 and 2003 year classes, which were less than the 2004 year-class strength (Table 6). Whereas, year-class strength, as measured by the seine samples, were similar for the 2002 and 2004 year classes, which were greater than the

2003 year-class strength (Table 2). Continued monitoring of striped bass year-class strength using both gears is recommended under F-50-R, Project 20.

The precision of the March gill-net samples met the target level of precision ($CV_{\bar{x}}$=0.20) in only three of nine samples (Table 6). Additional replicates are needed to improve the precision of the gill-net sampling.

D. Conclusions/Recommendations

- Spawning locations in both rivers varied by year and flow. Primary spawning sites on the Red River were between 60-69 km, 90-109 km, and 140-159 km upstream of the lake; Washita River spawning locations were between 70-89 km and 100-109 km upstream (see Addendum).
- Gelatin beads were greater in diameter and lower in specific gravity than striped bass eggs from the Red and Washita rivers (see Addendum).
- Drift rates of striped bass eggs and gelatin beads did not differ significantly; consequently, gelatin beads were deemed appropriate as striped bass egg surrogates (see Addendum).
- Sampling efficiency of the drift nets varied by site and flow rates ranging from 0.001% to 0.336% for the Red River and from 0.032% to 0.287% for the Washita River (see Addendum).
- Comparison of efficiency-corrected catch rates of striped bass eggs between rivers indicated that more striped bass eggs are produced in the Washita River than in the Red River (see Addendum).
- Low flows were more detrimental to striped bass egg production in the Red River than in the Washita River as evidenced by the 2003 data (see Addendum). This is

likely due to morphological differences between rivers; the Red being a shallow, braided channel while the Washita has a deeper, more channelized basin (see Addendum).

- Statistical comparison of egg numbers produced by river by year failed to detect differences less than 300% and consequently may not be a good measure of striped bass recruitment in Lake Texoma (see Addendum).
- No between-arm differences in juvenile striped bass abundance were noted statistically in the 2000-2002 samples. Seine catches in the Washita River arm were higher than in the Red River arm in 2003. Flows in the Red River arm never exceeded 800 cfs in 2003. Catches of striped bass were higher in the Red River arm in 2004.
- No among-year differences were found in seine catches of juvenile striped bass in the Washita River arm, 2000-2004. Among-year differences in seine catch in the Red River arm were evident with 2003 being the lowest and 2004 being the highest.
- Age-0 shad abundance, as measured by surface-set gill-net samples, was high and dominated by threadfin shad even following a partial winterkill in 2000-2001.
- No between-arm differences in age-0 shad abundance were seen in 2000, 2001, 2002, nor 2004. Catches of age-0 shad were higher in the Red River arm in 2003. No among year differences were seen when catches of threadfin and gizzard shad were combined, 2001-2004.
- The relative between-arm differences in March gill-net samples mirrored the differences seen in the respective seine samples for the 2002 and 2003 year

classes of striped bass. However, this relation did not hold for the 2004 year class.

- Samples sizes for the seine and March gill-net samples for age-0 striped bass should be increased to reach a target precision of $CV_{\bar{x}}=0.20$.
- Continued seine and gill-net sampling for age-0 striped bass along with forage monitoring using surface-set gill nets is recommended under F-50-R, Project 20.
- Correlations between inflows and year-class strength by arm and numbers of age-0 striped bass and mean length will be explored with the availability of additional data.

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Table 1. Within-year differences in catch per unit effort (CPUE; number/haul) from shoreline seining of age-0 striped bass from the Red River arm and Washita River arm of Lake Texoma, Oklahoma, 2000-2004. N=number of hauls, $CV_{\bar{x}}$=coefficient of variation of the mean. Mean CPUE within each year with different superscripts were statistically different (one-way ANOVA; $P \leq 0.05$). Median CPUE within each year with different upper case superscripts were statistically different (Wilcoxon Rank Sum Test; $P \leq 0.05$). *Data from 2000 and 2001 were collected under projects F-50-R, Project 13 and F-50-R, Project 14, respectively.

YEAR	ARM	N	MIN	MAX	MEDIAN	MEAN	$CV_{\bar{x}}$
2000*	Red River	17	1.0	110.0	7.0^{A}	22.2^{a}	0.37
	Washita	13	0	100.0	9.0^{A}	34.8^{a}	0.31
2001*	Red River	40	0	306.0	30.5^{A}	61.5^{a}	0.21
	Washita	40	0	106.0	23.0^{A}	28.5^{a}	0.15
2002	Red River	20	1.5	210.0	26.8^{A}	70.2^{a}	0.22
	Washita	20	7.5	151.5	22.5^{A}	39.3^{a}	0.22
2003	Red River	20	0	11.5	1.8^{A}	2.9^{a}	0.27
	Washita	20	0	271.0	30.0^{B}	52.2^{b}	0.30
2004	Red River	20	44.5	665.0	121.3^{A}	221.0^{a}	0.29
	Washita	20	0	88.5	36.8^{B}	33.9^{b}	0.17

Table 2. Among-year differences in catch per unit effort (CPUE; number/haul) from shoreline seining of age-0 striped bass from the Red River arm, Washita River arm and arms combined of Lake Texoma, Oklahoma, 2000-2004. N=number of hauls, $CV_{\bar{x}}$=coefficient of variation of the mean. Mean CPUE within each arm with different lower case superscripts were statistically different (one-way ANOVA of $\log_n$CPUE+1; $P \leq 0.05$). Median CPUE within each year with different upper case superscripts were statistically different (Kruskal-Wallis nonparametric one-way ANOVA; $P \leq 0.05$). *Data from 2000 and 2001 were collected under projects F-50-R, Project 13 and F-50-R, Project 14, respectively.

YEAR	N	MIN	MAX	MEDIAN	MEAN	$CV_{\bar{x}}$
			Red River Arm			
2000*	17	1.0	110.0	7.0^{BC}	22.2^{a}	0.37
2001*	40	0	100.0	9.0^{B}	61.5^{ab}	0.21
2002	20	1.5	210.0	26.8^{AB}	70.2^{b}	0.22
2003	20	0	11.5	1.8^{C}	2.9^{c}	0.27
2004	20	44.5	665.0	121.3^{A}	221.0^{d}	0.20
			Washita River Arm			
2000*	13	0	100.0	9.0^{A}	34.8^{a}	0.31
2001*	40	0	106.0	23.0^{A}	28.5^{a}	0.15
2002	20	7.5	151.5	22.5^{A}	39.3^{a}	0.22
2003	20	0	271.0	30.0^{A}	52.2^{a}	0.30
2004	20	0	88.5	36.8^{A}	$33..9^{a}$	0.16
			Arms Combined			
2000*	30	0	110.0	8.0^{AB}	27.7^{ab}	0.24
2001*	80	0	306.0	26.0^{A}	45.0^{ac}	0.15
2002	40	1.5	210.0	24.5^{AC}	54.7^{cd}	0.17
2003	40	0	271.0	3.0^{B}	27.5^{b}	0.32
2004	40	0	665.0	65.8^{C}	127.5^{d}	0.21

Table 3. Catch per unit effort (CPUE; number/net-night) from surface-set gill nets of shad spp.(SS), gizzard shad (GS), and threadfin shad (TS) from the Red River arm and Washita River arm of Lake Texoma, Oklahoma, 2001-2004. N=number of net sets, $CV_{\bar{x}}$=coefficient of variation of the mean.Means within the same column within each year with different superscripts were statistically different (one-way ANOVA of $\log_n$CPUE+1; $P \leq 0.05$). *Data from 2001 were collected under project F-50-R, Project 14.

YEAR	ARM		SS	GS	TS
2001*	Red River	N=19			
		Mean	830.6[a]	301.5[a]	529.1[a]
		$CV_{\bar{x}}$	0.11	0.21	0.12
	Washita	N=19			
		Mean	727.8[a]	56.8[b]	671.0[a]
		$CV_{\bar{x}}$	0.17	0.28	0.18
2002	Red River	N=20			
		Mean	874.8[a]	70.3[a]	804.5[a]
		$CV_{\bar{x}}$	0.19	0.19	0.20
	Washita	N=20			
		Mean	1092.5[a]	144.8[a]	935.0[a]
		$CV_{\bar{x}}$	0.16	0.24	0.19
2003	Red River	N=20			
		Mean	1079.9[a]	138.9[a]	941.0[a]
		$CV_{\bar{x}}$	0.13	0.27	0.14
	Washita	N=20			
		Mean	716.5[b]	21.0[b]	635.5[a]
		$CV_{\bar{x}}$	0.14	0.26	0.14
2004	Red River	N=20			
		Mean	1037.0[a]	210.8[a]	826.2[a]
		$CV_{\bar{x}}$	0.09	0.34	0.10
	Washita	N=20			
		Mean	998.4[a]	78.6[b]	919.8[a]
		$CV_{\bar{x}}$	0.11	0.20	0.12

Table 4. Catch per unit effort (CPUE; number/net-night) of age-0 shad spp., gizzard shad, and threadfin shad in September gill-net samples from Lake Texoma, Oklahoma 2001-2004. N=number of net sets, $CV_{\bar{x}}$=coefficient of variation of the mean. Medians within the same column within each year with different superscripts were statistically different (Kruskal-Wallis nonparametric one way ANOVA; $P \leq 0.05$). *Data from 2001 were collected under project F-50-R, Project 14.

YEAR	N	MIN	MAX	MEDIAN	MEAN	$CV_{\bar{x}}$
			Shad Species Combined			
2001*	38	49.5	1897.5	646.7[a]	779.2	0.10
2002	40	121.6	3904.5	763.9[a]	983.6	0.12
2003	40	39.2	2331.8	737.3[a]	898.2	0.10
2004	40	203.5	1944.0	984.0[a]	1017.7	0.07
			Gizzard Shad			
2001*	38	4.5	1224.0	78.8[a]	179.1	0.21
2002	40	1.2	704.5	72.7[ab]	107.6	0.18
2003	40	0	644.8	28.8[b]	80.0	0.26
2004	40	1.3	471.6	107.9[a]	144.7	0.15
			Threadfin Shad			
2001*	38	45.0	1761.0	563.9[a]	600.1	0.11
2002	40	46.8	3751.5	609.0[ab]	869.7	0.13
2003	40	37.9	2141.1	698.3[ab]	818.2	0.10
2004	40	84.6	1850.3	809.9[b]	873.0	0.08

Table 5. Catch per unit effort (CPUE; number/net-night) of age-0 striped bass in March gill-net samples from the Red River arm and Washita River arm of Lake Texoma, Oklahoma, 2002-2004. N=number of net sets, $CV_{\bar{x}}$=coefficient of variation of the mean. Medians within the same column within each year with different superscripts were statistically different (Wilcoxon rank sum test; $P \leq 0.05$).

YEAR CLASS	ARM	N	MIN	MAX	MEDIAN	MEAN	$CV_{\bar{x}}$
2002	Red	20	0.0	70.9	9.2^{a}	13.0	27.5
	Washita	20	0.0	19.4	5.1^{a}	6.3	22.0
2003	Red	20	0.0	8.5	1.2^{a}	1.8	28.8
	Washita	20	3.8	53.1	14.2^{b}	22.0	17.0
2004	Red	20	0.0	50.4	10.5^{a}	15.3	19.7
	Washita	20	0.0	79.6	18.4^{a}	21.5	21.8

Table 6. Catch per unit effort (CPUE; number/net-night) of age-0 striped bass in March gill-net samples from Lake Texoma, Oklahoma 2002-2004. N=number of net sets; $CV_{\bar{x}}$=coefficient of variation of the mean. Medians within the same column within each year with different superscripts were statistically different (Wilcoxon rank sum test; $P \leq 0.05$).

YEAR CLASS	ARM	N	MIN	MAX	MEDIAN	MEAN	$CV_{\bar{x}}$
2002	Red	20	0.0	70.9	9.2^{a}	13.0	27.5
2003		20	0.0	8.5	1.2^{b}	1.8	28.8
2004		20	0.0	50.4	10.5^{a}	15.3	19.7
2002	Washita	20	0.0	19.4	5.1^{a}	6.3	22.0
2003		20	3.8	53.1	14.2^{b}	22.0	17.0
2004		20	0.0	79.6	18.4^{b}	21.5	21.8
2002	Combined	40	0.0	70.9	6.0^{a}	9.7	20.4
2003		40	0.0	53.1	5.6^{a}	11.9	20.7
2004		40	0.0	79.6	13.8^{b}	18.4	15.1

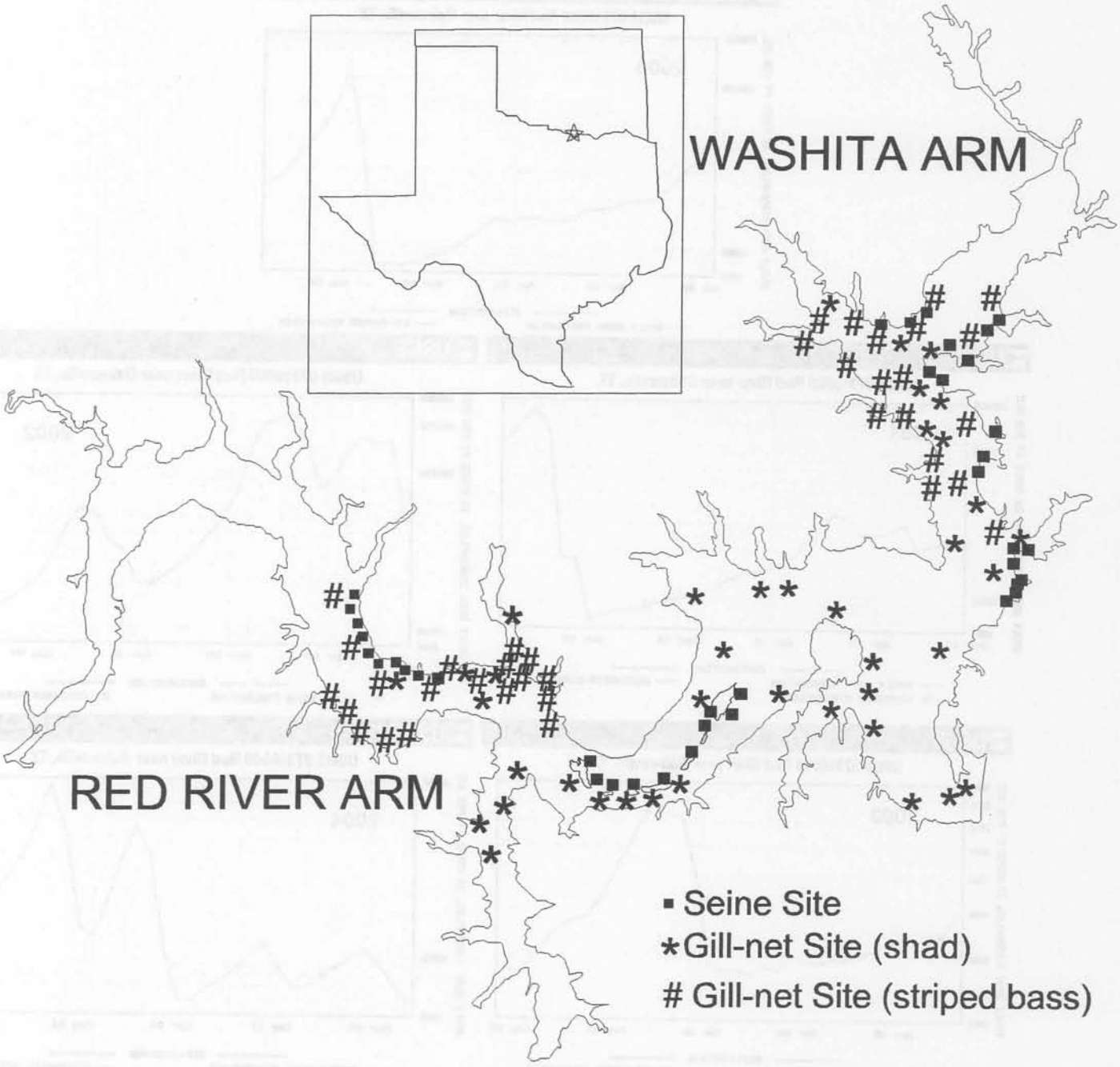


Figure 1. Seine and gill-net sampling sites on Lake Texoma, Oklahoma.

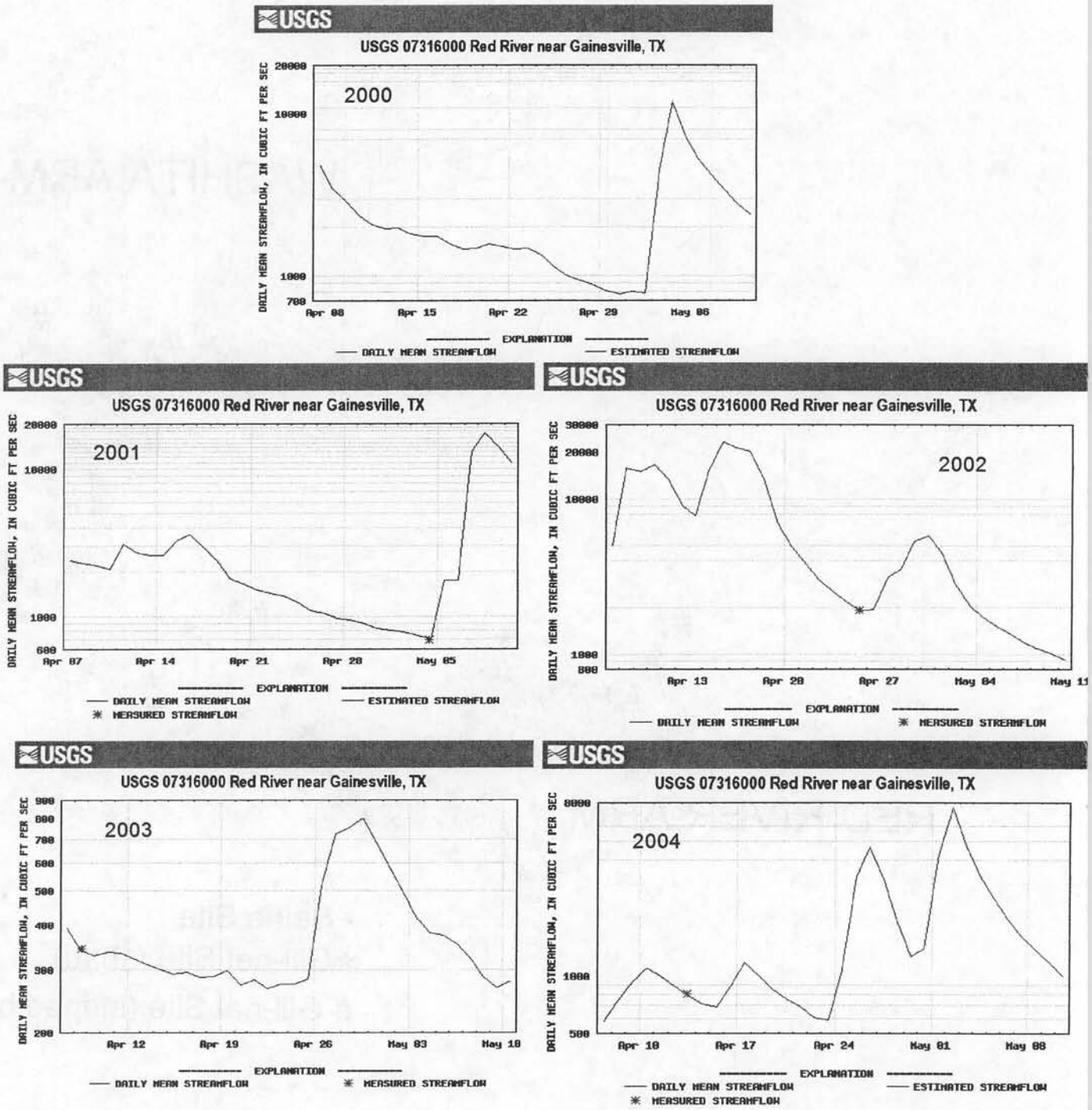


Figure 2. Daily stream flow measured at the Gainesville, TX USGS gauging station during the striped bass spawning season (7 April - 10 May) 2000-2004.

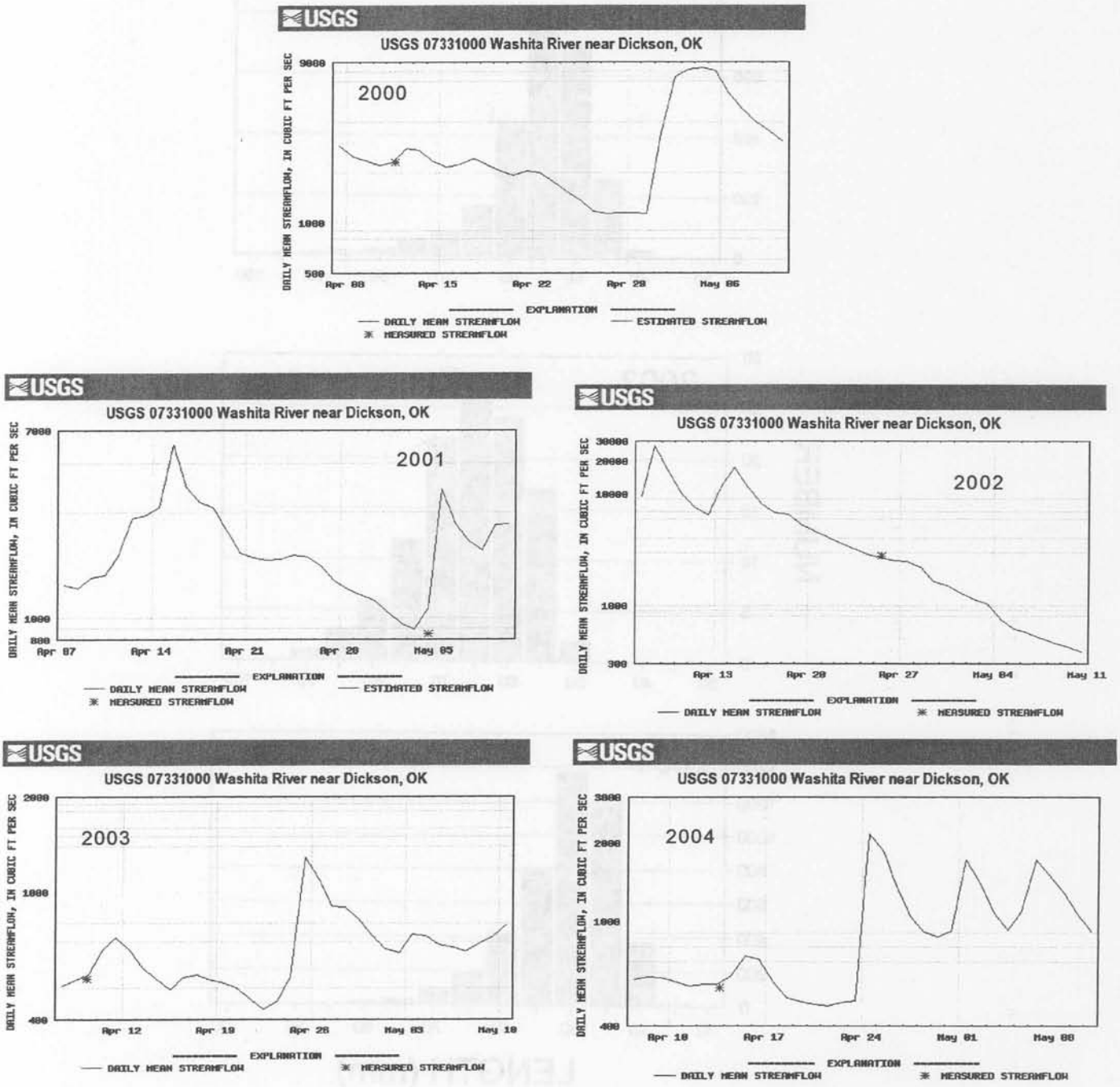


Figure 3. Daily stream flow measured at the Dickson, OK USGS gauging station during the striped bass spawning season (7 April - 10 May) 2000-2004.

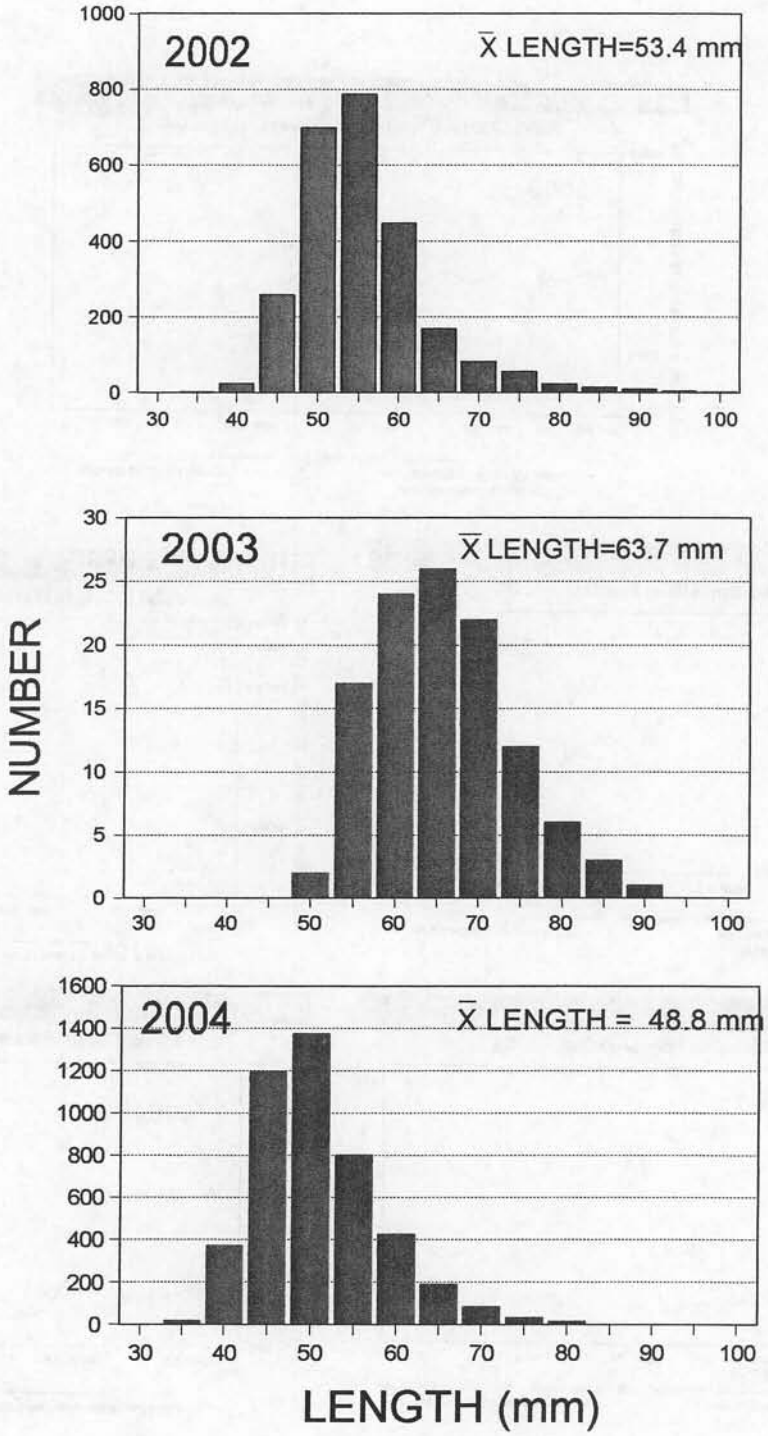


Figure 4. Length frequency of age-0 striped bass from the June, 2002-2004 seine samples from the Red River arm of Lake Texoma, Oklahoma.

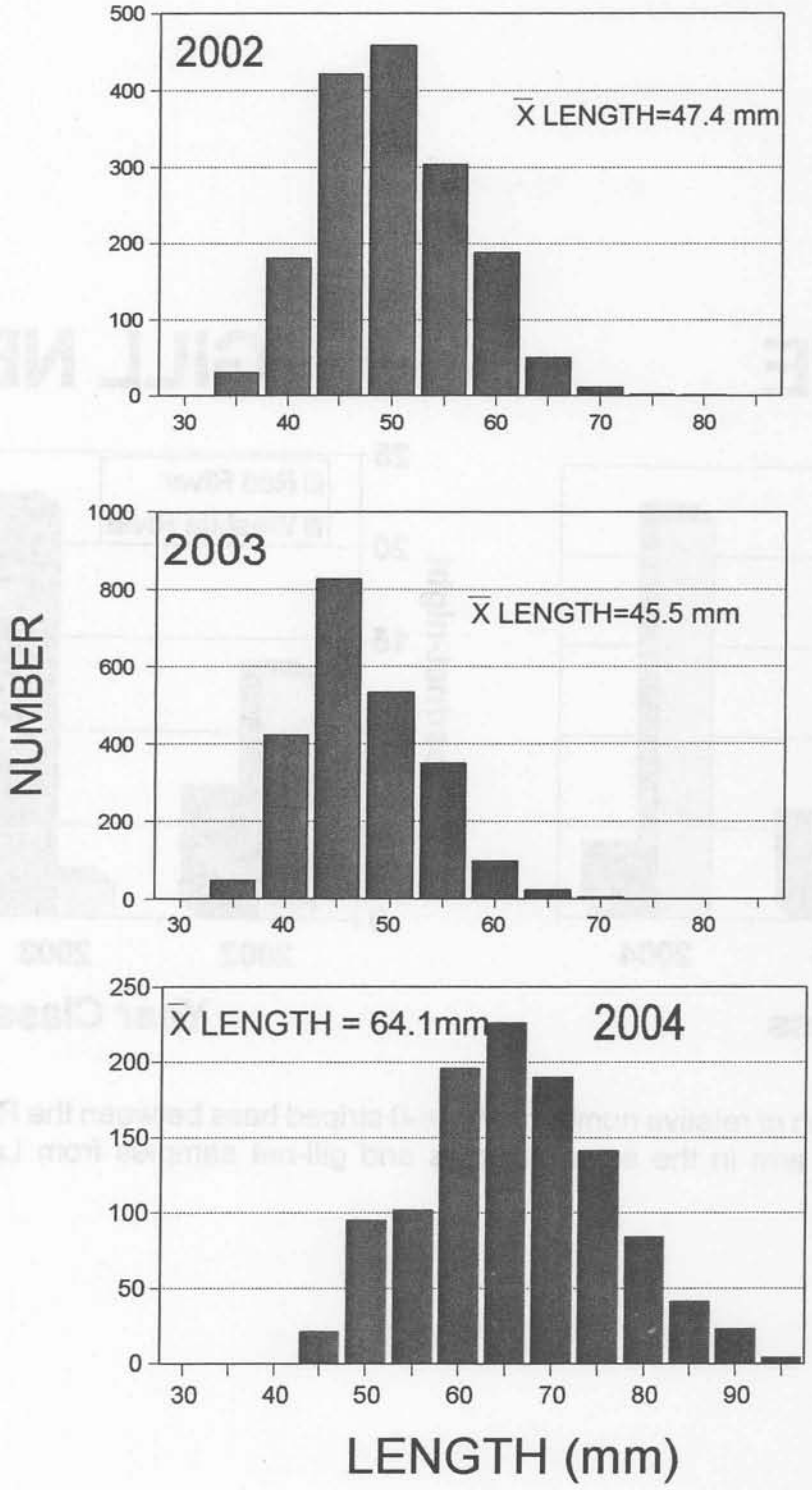
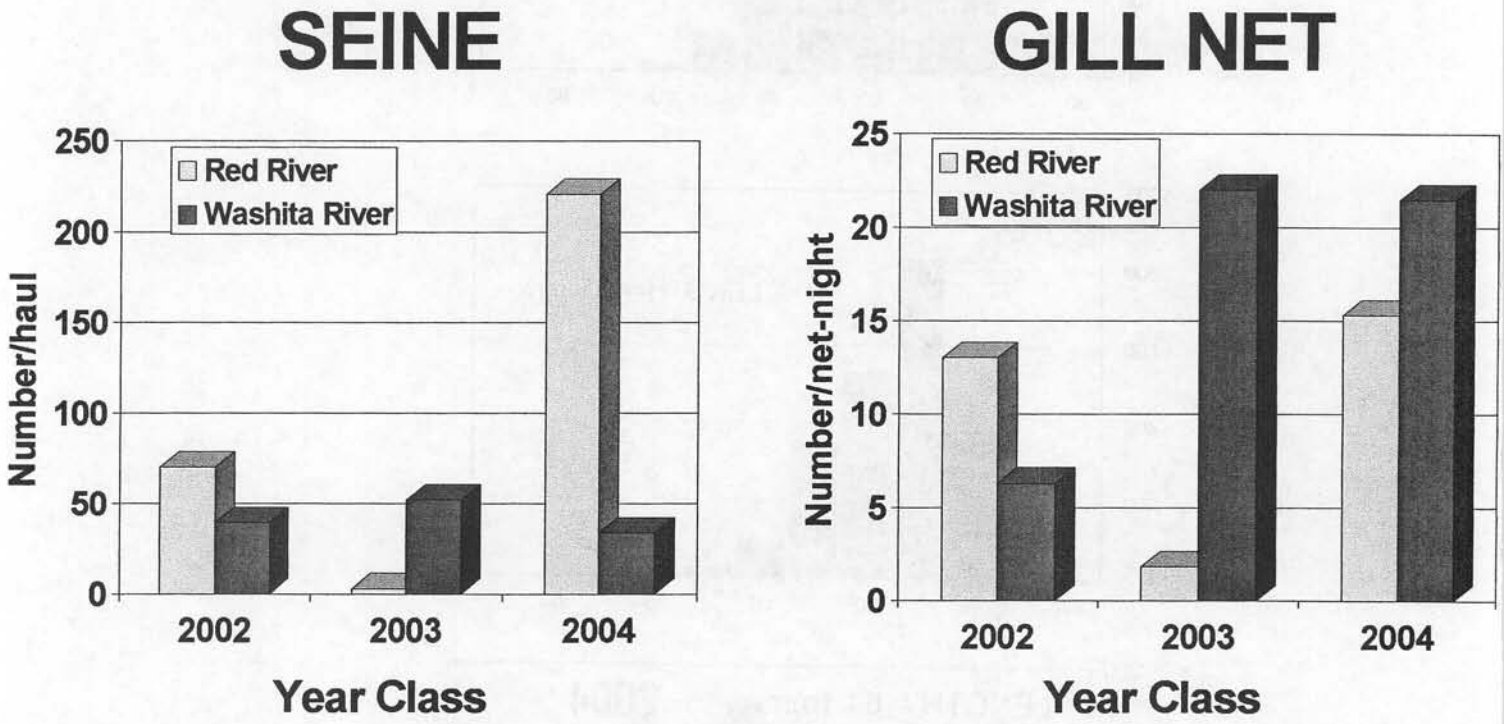


Figure 5. Length frequency of age-0 striped bass from the June, 2002-2004 seine samples from the Washita River arm of Lake Texoma, Oklahoma



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UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

USE OF GELATIN BEADS AS STRIPED BASS *MORONE SAXATILIS* EGG SURROGATES FOR ESTIMATION OF EGG PRODUCTION IN THE RED AND WASHITA RIVERS

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

ZOOLOGY

By

Robert G. Ryan
Norman, Oklahoma
2004

USE OF GELATIN BEADS AS STRIPED BASS *MORONE SAXATILIS* EGG SURROGATES FOR ESTIMATION OF EGG PRODUCTION IN THE RED AND WASHITA RIVERS

A THESIS APPROVED FOR THE DEPARTMENT OF ZOOLOGY

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ACKNOWLEDGEMENTS

I wish to thank the Oklahoma Department of Wildlife Conservation, especially all the staff of the Fisheries Research Laboratory for their direction and assistance in all aspects of completing this project. I am grateful for the funding provided by the Oklahoma Department of Wildlife Conservation, the Oklahoma Biological Survey, and the Department of Zoology. I also thank my principle advisor Dr. Bill Shelton for his guidance throughout my graduate education. I appreciate the participation of my graduate committee members Dr. David Hambright and Dr. Bill Matthews. Thanks to Bill Baker for providing the starting point for this project as well as advice, assistance, and good humor. Lastly, I thank my wife and parents for always providing support and encouragement.

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INTRODUCTORY STATEMENT

This thesis is composed of two manuscripts format suitable for submission to an American Fisheries Society publication. Each manuscript is complete without supporting materials. The order and arrangement for each manuscript is text, literature cited, tables, and figures.

CHAPTER I

EVALUATION OF GELATIN BEADS AS SURROGATE STRIPED BASS EGGS

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Abstract - Gelatin beads were used as striped bass egg surrogates for determination of striped bass egg sampling efficiencies in the two major tributaries, the Red and Washita Rivers, of Lake Texoma, Oklahoma/Texas. Gelatin beads potentially differed from striped bass eggs of the Red and Washita Rivers in diameter and specific gravity. These physical differences may have influenced efficiency measurements determined using gelatin beads. The objectives of this investigation were to: 1) evaluate physical characteristics of gelatin beads and striped bass eggs from the Lake Texoma system; 2) compare directly drift rates of Red and Washita River striped bass egg and gelatin beads; and 3) evaluate the potential effects of density differences on drift depth. Eggs and gelatin beads were compared by diameter and specific gravity. Gelatin bead and striped bass egg drift rates were compared by timing travel in an experimental tank. The effect of density differences on drift position vertically within the water column was determined by evaluating vertical drift position of gelatin beads differing in density in an experimental tank. Gelatin beads were greater in diameter and lower in specific gravity than striped bass eggs from the Red and Washita Rivers. Gelatin bead and Washita River striped bass egg drift rates did not differ significantly. Gelatin beads of lesser density were significantly more buoyant than those of greater density. Results represented the potential for gelatin beads to travel higher in the water column than striped bass eggs. Despite dissimilarities in gelatin beads and striped bass eggs, gelatin beads were considered functional tools for determining striped bass egg sampling efficiency.

INTRODUCTION

The Lake Texoma striped bass *Morone saxatilis* fishery is one of Oklahoma's most valuable fisheries contributing significantly to local economy (Schorr et al. 1995). Not only is this fishery monetarily valuable, but it also is one of only about ten naturally reproducing inland striped bass populations in North America (Stevens 1984). Despite the unique character of this population, little is known about its reproductive dynamics.

Striped bass spawn in the Red and Washita Rivers, tributaries of Lake Texoma, but the relative contribution of each tributary to recruitment is poorly understood (Baker 2003). Striped bass recruitment is potentially threatened by a proposed water diversion and salinity reduction project on the Red River (Jeff Boxrucker, Senior Biologist, Oklahoma Department of Wildlife Conservation, personal communication). One approach to better understanding this population is to define the importance its two major tributaries in supporting reproduction.

Estimating striped bass egg production from each river is one step in determining the contributions of the Red and Washita Rivers to the Lake Texoma striped bass population. Morphological variability between rivers associated with river hydrology indicates the potential for differences in striped bass egg sampling efficiency in the Red and Washita Rivers. In order to compare egg production between rivers of dissimilar channels, determination of sampling efficiency is necessary. Sampling efficiency can be defined using surrogate eggs that resemble the physical characteristics of striped bass eggs in release-recapture procedures (Reinert et al. 2004). Efficiencies can be applied to egg collections taken in these rivers for relative comparisons of egg production.

I used gelatin beads (Technology Flavors and Fragrances, INC., Amityville, New York) as surrogate striped bass eggs to determine striped bass egg sampling efficiency in the Red and Washita Rivers. Sampling efficiency was defined as the percentage of striped bass eggs captured from the total number of striped bass eggs passing a given sample site during a 10-min sample effort. Gelatin beads consisted of gellan gum, an extracellular polysaccharide material used in the food industry as a thickening and gelling agent (Food Technology 1990). Gelatin beads have been shown to be similar in physical characteristics such as density and diameter to striped bass eggs (Davin et al. 1999; Reinert et al. 2004). Physical characteristics of density and diameter relate to the nature in which semi-buoyant eggs and gelatin beads drift downstream (Bergey et al. 2003; Davin et al. 1999).

Gelatin beads were considered adequate striped bass egg surrogates in the Savannah River system, Georgia, where they were used in determining striped bass egg drift rate and striped bass egg sampling efficiency (Davin et al. 1999; Reinert et al. 2004). However, gelatin beads were potentially less similar to striped bass eggs of the Red and Washita Rivers. Bergey et al. (2003) reported mean (± SD) Savannah River striped bass egg diameter to be 2.77 ± 0.19 mm. Baker (2003) reported mean (± SD) striped bass egg diameters of the Red and Washita Rivers to be only 1.50 ± 0.10 mm and 1.66 ± 0.11 mm, respectively. Gelatin beads used in the Savannah River investigations (yellow, red, and purple) had mean diameters ranging from approximately 4 to 5 mm, being greater in size than striped bass eggs of either the Savannah River or Lake Texoma systems (Baker 2003; Reinert et al. 2004).

Striped bass and gelatin bead physical differences may have affected both the depth of drift within the water column and drift rate. Physical differences between gelatin beads and striped bass eggs in the Red and Washita River may have influenced the accuracy of efficiency measures. Concerns of drift depth existed because sampling associated with efficiency measures was conducted only within the top 0.5 m of the water column. Therefore, capture rate would be influenced by the buoyancy of the object. If gelatin beads were more or less buoyant than striped bass eggs, efficiency measures might be over or underestimated.

Physical differences between gelatin beads and striped bass eggs of the Red and Washita Rivers might have affected egg drift rate estimates. Estimation of striped bass egg drift rate was important to better understanding recruitment in the Red and Washita Rivers. Drift rate of striped bass eggs was one item of information needed to calculate spawning sites of captured eggs.

The objectives of this investigation were to: 1) evaluate physical differences in gelatin beads and striped bass eggs from the Lake Texoma system; 2); compare directly drift rates of Red and Washita River striped bass egg and gelatin beads; and 3) evaluate the potential effects of density differences on drift depth.

METHODS

PHYSICAL COMPARISONS

I measured gelatin bead and striped bass egg diameter and specific gravity to evaluate the significance of physical differences between gelatin beads and striped bass eggs of the Red and Washita Rivers. Both orange and yellow gelatin beads were used in physical comparisons. I collected striped bass eggs used in specific gravity

measurements from the Red and Washita Rivers using conical plankton nets fished just below the water's surface. Striped bass eggs were collected in April of 2003 and 2004. Striped bass eggs were transported in zip lock bags containing ambient river water placed in coolers to the Oklahoma Department of Wildlife Conservation Fisheries Research Laboratory Norman, Oklahoma. Only viable striped bass eggs were used in physical comparisons. Striped bass eggs were assumed to be fully water hardened when measurements were taken at the laboratory.

Diameter and specific gravity of striped bass eggs were promptly measured upon arrival at the laboratory. I used diameters of Red and Washita River fully swelled striped bass eggs previously reported by Baker (2003) in diameter comparisons. I measured gelatin bead diameters to the nearest 0.01 mm using a Bausch and Lomb dissecting microscope (Bausch and Lomb Inc., Rochester, New York) and EPIX XCAP imaging software (EPIX, Inc., Buffalo Grove, Illinois).

Gelatin beads arrived from the supplier packed in a sucrose solution for shipment and storage. Reinert et al. (2004) reported specific gravities of gelatin beads were greatest when beads were tested directly following removal from packing solution and that washing in water, reduced density to a level more closely resembling striped bass egg density. Therefore, prior to specific gravity measurement, I strained and washed gelatin beads. Gelatin beads were washed in 20-L buckets by flushing with non-chlorinated well water from the bottom up until gelatin beads exhibited a noticeable increase in buoyancy, typically two to three hours. Non-chlorinated well water had a salinity of 0.04‰. Gelatin beads were stored in 20-L buckets with non-chlorinated wash water for storage prior to use.

I determined specific gravity of striped bass eggs using a series of saline solutions of known specific gravity as described in Hurley (1991). I used laboratory grade sodium chloride dissolved in distilled water to create solutions of known specific gravity (Wolf et al. 1978). Solutions were mixed in specific gravity increments of 0.0005. Gelatin beads and striped bass eggs were placed individually into specific gravity solutions. Gelatin beads and striped bass eggs were considered equal in specific gravity to solutions in which they were neutrally buoyant or between solutions in which they experienced positive and negative buoyancy. Gelatin beads and striped bass eggs remained in specific gravity solutions for only several seconds while their position was evaluated. I was careful to remove excess liquid from objects prior to and between placements in specific gravity solutions. Specific gravity was determined at room temperature (~ 20 °C).

I determined specific gravities from each of six orange and nine yellow individually washed buckets of gelatin beads. Ten gelatin beads per bucket were evaluated. I compared mean specific gravities of orange and yellow ten-bead samples to specific gravities of 15 Red River and 15 Washita River striped bass eggs.

Diameter and specific gravity data were not normally distributed (Shapiro-Wilks test; $P \leq 0.05$). Log_{10}-transformation did not adequately normalize data. Consequently, I used a Kruskal-Wallis one-way nonparametric ANOVA ($P \leq 0.05$) to compare diameters and specific gravities of gelatin beads and striped bass eggs. I used a Kruskal-Wallis all-pairwise comparison test ($P \leq 0.05$) to define differences following significant results in analysis of variance procedures.

DRIFT RATE

I directly compared drift of gelatin beads and striped bass eggs in the laboratory to determine the possibility of drift rates differing due to physical differences of both diameter and density. Gelatin beads and striped bass eggs were timed during travel around a circular tank. I compared drift of gelatin beads, Washita River striped bass eggs, and Oklahoma Department of Wildlife Conservation Byron Hatchery (Byron, Oklahoma) striped bass eggs. Red River striped bass eggs were not included in laboratory drift comparisons due to difficulties in collection and successful transport of eggs.

Striped bass eggs were collected and transported for use in drift comparisons from the Washita River in April of 2003 and 2004 using protocol detailed above. In 2003, I also used striped bass eggs from Byron Hatchery in drift comparisons. Hatchery striped bass eggs were smaller in diameter (1.31 ± 0.06 mm (± SD)) and greater in specific gravity (1.0071 ± 0.00035 (± SD)) than Red or Washita River striped bass eggs. I determined mean diameter and specific gravity of hatchery striped bass eggs following protocol described previously. I used only viable swelled eggs in drift rate comparisons.

I used a circular tank of 3.47 m peripheral circumference and 1.76 m internal circumference in drift comparisons (Figure 1). The internal circumference of the tank was formed by placing a cylindrical structure in the center of the tank. A water pump was placed in the internal cylindrical structure to create water movement. Drift comparisons were conducted at water depths of 19 cm and 28 cm in 2003 and 2004, respectively. Water depth was increased to reduce the potential for drifting objects to interact with the tank bottom. I released striped bass eggs and gelatin beads individually

and timed their travel of the distance around the tank. Mean drift time (s) represented one to several trips around the tank. No water measures were taken in association with drift comparisons. In 2003, I compared drift of gelatin beads, Washita River striped bass eggs, hatchery striped bass eggs, and striped bass egg drift times of both sources combined. In 2004, I compared only drift of gelatin beads and Washita River striped bass eggs.

Drift data collected in 2003 were not normally distributed (Shapiro-Wilks test; $P \leq 0.05$). Log_{10}-transformation failed to adequately normalize data. Consequently, I compared 2003 mean drift data using a Kruskal-Wallis one-way nonparametric ANOVA ($P \leq 0.05$). I evaluated significant tests using a Kruskal-Wallis all-pairwise comparison test ($P \leq 0.05$). Drift data from 2004 were normally distributed (Shapiro-Wilks test; $P \leq 0.05$). I compared mean drift times using a two-sample t-test ($P \leq 0.05$).

Travel Position

In the laboratory, I evaluated the potential for differences in gelatin bead and striped bass egg density to significantly effect drift depth within the water column. I used gelatin beads of different densities drifted in an experimental tank to evaluate this potential. I hypothesized that gelatin beads of greater specific gravity would travel lower in the water column.

I evaluated gelatin bead drift depth by timing gelatin bead drift rates. I assumed, that given water velocities that differed by water depth, I could detect differences in drift rates of gelatin beads that travel at different depths due to density differences.

The density of gelatin beads was manipulated by soaking them in solutions of different salinity for several days. Gelatin beads absorbed the liquid in which they were soaked. Therefore, I was able to influence their density by soaking them in differing salinity of solutions. Gelatin beads were first rinsed several times with distilled water to remove the sucrose solution in which they came packed. Following rinsing, gelatin beads were soaked in salinity solutions of 0.0‰ and 4.0‰ to continue the washing process and manipulate density of gelatin beads.

I compared gelatin bead physical characteristics of density and diameter to define differences between specific gravity treatments and evaluate potential differences in different colored gelatin beads. Specific gravity of gelatin beads used in trials was determined using protocols described above. Gelatin bead diameters were previously reported in the description of physical characteristics above and were assumed to be relatively stable despite density manipulation.

I used the circular tank described above to conduct evaluations of gelatin bead drift depth. Three water levels (15.0 cm, 28.0 cm, and 41.0 cm) were used as treatments to evaluate the influence of water depth within the tank on gelatin bead drift rate. I based the range of depth on maximum and minimum tank depth allowing for proper operation of the pump system.

I measured water velocity (m/s) to provide evidence that water velocity differed by depth and for use in defining gelatin bead drift rate. I made velocity measurements using a Model 2000 Flow-Mate digital flow meter (Marsh-McBirney, Inc., Frederick, MD) three times during each 60-gelatin bead set. All velocity measurements were made at a standardized location within the experimental tank. At the standardized location,

velocity measurements were taken at 20% and 80% of water depth, at each of three positions across the tank channel (inside, middle, and outside). I averaged measures among positions at depths to define differential velocity based on depth and averaged velocity measures among positions and depths for use in determining gelatin bead drift rate. Mean water velocity ranged from 0.16 to 0.20 m/s. Hurley (1991) indicated 0.03 to 0.061 m/s is necessary to keep striped bass eggs suspended. Tank velocities were less than river velocities measured in Chapter II.

I determined mean drift rate of gelatin beads from three timed drifts around the tank circumference. Beads were released individually and timed for travel around the experimental tank. I determined drift rate (m/s) using the average distance (m) of peripheral and inner tank circumferences and travel time (s). For comparison among treatments in which water velocity may vary, rate was converted to a percent of mean water velocity.

I used a randomized experimental design to compare travel rates of gelatin beads by treatments of density and tank depth. Gelatin beads were randomly selected from storage containers and assigned to density treatments. Thirty gelatin beads of each color (yellow and orange) were randomly selected from density treatments to run in each of six treatment combinations. Treatment combinations included two levels of specific gravity and three depth combinations.

Comparison of gelatin bead drift rate by colors was completed to evaluate the effect of any undetected differences in orange and yellow gelatin beads. I compared drift rates by gelatin bead color across treatments using a Wilcoxon rank sum test ($P \leq 0.05$). Drift rates by gelatin bead color were not normally distributed (Shapiro-Wilks test;

$P \leq 0.05$). Log_{10}-transformation failed to normalize data adequately. Gelatin bead drift rates were combined by color for analysis of treatment effects after finding no significant differences in drift rates by color across treatments.

Water velocity measurements were not normally distributed (Shapiro-Wilks test; $P \leq 0.05$). Log_{10}-transformation failed to normalize data adequately. Consequently, I compared velocity measures at 20% and 80% of water depth using a non-parametric Wilcoxon signed rank test ($P \leq 0.05$). Tests were used to define differential water velocities between depths and the resulting potential for variable travel rate due to drift position differences vertically within the water column.

I evaluated the effects of salinity and depth treatments using two-way ANOVA ($P \leq 0.05$) (SAS, version 8.1, PROC GLM). Drift rate was model as the dependant variable. Categorical dummy variables were used to describe treatments of salinity and depth.

I compared drift rates across depth treatments to evaluate significant findings of depth treatment effect. Log_{10}-transformed data were adequately normalized. Drift rate data across depth treatments were compared using one-way ANOVA ($P \leq 0.05$). I used a Tukey HSD all-pairwise comparison test ($P \leq 0.05$) to define significant differences in depth treatments.

RESULTS AND DISCUSSION

PHYSICAL COMPARISONS

No difference in diameter was found between orange and yellow gelatin beads (Kruskal-Wallis one-way nonparametric ANOVA; df = 3; F = 694; $\underline{P}<0.0001$) (Table 1), averaging 5.04 ± 0.12 mm (95% C. I.) and 4.87 ± 0.09 mm respectively. Orange and yellow gelatin beads were significantly larger than mean striped bass eggs of the Red and

Washita Rivers at 1.48 mm and 1.66 mm, respectively (Kruskal-Wallis one-way nonparametric ANOVA; df = 3; F = 694; $\underline{P}<0.0001$) (Table 1). Striped bass eggs of the Red River were smaller than eggs of the Washita River as demonstrated by Baker (2003).

Striped bass egg specific gravity averaged 1.0111 ± 0.0011 (95% C. I.) and 1.0067 ± 0.0007 (95% C. I.) in the Red and Washita Rivers, respectively. Specific gravity of orange and yellow gelatin beads averaged 1.0017 ± 0.0007 (95% C. I.) and 1.0018 ± 0.0004 (95% C. I.), respectively. Striped bass eggs differed by river and from gelatin beads (Kruskal-Wallis one-way nonparametric ANOVA; df = 3; F = 75.7; $\underline{P}<0.0001$) (Table 1). Gelatin beads did not differ by color.

Differences in measures of specific gravity implied that gelatin beads were more buoyant than striped bass eggs of the Red and Washita River. Gelatin beads because of greater buoyancy may have misrepresented drift patterns and rates striped bass egg.

Red and Washita River striped bass eggs were not typical of striped bass eggs found in other populations in North America. Bergey et al. (2003) indicated mean egg diameter and specific gravity of striped bass eggs from nine different Atlantic coast populations ranged from 1.84 to 3.67 mm and from 1.0087 to 1.0010, respectively. Eggs of the Red and Washita Rivers were smaller than those reported by Bergey et al. (2003). Washita River eggs were within the range of specific gravity described, but Red River eggs were considerably greater in specific gravity. Mansueti (1958) suggested egg diameter was affected by water salinity. Salinity influences chorion expansion and contraction through osmosis. Given the relatively high salinity of the Red and Washita Rivers, small egg diameter is not surprising. Albrecht (1964) suggested specific gravity

is negatively correlated to egg diameter. Red River eggs are both smaller in diameter and lower in specific gravity than Washita River eggs, supporting this suggestion.

DRIFT RATE

Timed drift among gelatin beads, Washita River striped bass eggs, hatchery striped bass eggs, and striped bass eggs combined by source was significantly different (Kruskal-Wallis nonparametric one-way ANOVA; df = 3; F = 3.32; P=0.0235) (Table 2). Pairwise comparisons indicated timed drift of 2003 Washita River striped bass eggs were not significantly different from gelatin beads or hatchery striped bass eggs. Hatchery striped bass eggs did travel at a significantly different rate than gelatin beads. However, striped bass eggs combined by source did not travel faster than gelatin beads. In 2004, timed drift comparisons of Washita River eggs and gelatin beads were not significantly different (two sample t-test; P=0.5600) (Table 3).

Differences in egg and bead physical properties indicated the potential for differential travel positions and non-comparable drift rates. However, under laboratory conditions, physical differences in eggs and gelatin beads did not suggest differences in drift rates with the exception of comparisons using hatchery eggs. If experimental conditions were applicable to natural systems, gelatin beads should act as appropriate surrogates for determination of egg drift rates under river conditions.

Difficulties in collection, transportation, and testing, did not allow Red River eggs to be included in laboratory comparisons of drift rate. Given the smaller diameter and significantly greater specific gravity of Red River eggs, an increased potential exists for both differential drift rates and travel positioning. Hatchery eggs were most closely

related to those of the Red River. Significant differences in gelatin bead and hatchery egg drift rates may reflect this potential. However, insignificant differences in combined egg group-gelatin bead comparisons suggested increased sample sizes might yield different results. Drift rate comparisons in 2004 supported the applicability of gelatin beads, as drift rates did not differ between gelatin beads and striped bass eggs.

TRAVEL POSITION

Gelatin beads soaked in 0.0‰ and 4.0‰ salinity treatments had mean specific gravities of 1.0013 ± 0.0001 (95% C. I.) and 1.0032 ± 0.0001 (95% C. I.), respectively. Gelatin bead diameter did not differ by color. Drift rates of gelatin beads compared by color across treatments were not significantly different (Wilcoxon rank sum test; P=0.4245) (Table 4).

Water velocity ranged from 0.15 m/s to 0.24 m/s. Velocity measurements at 20% and 80% of water depth were significantly different in depth treatments of 28.0 cm and 41.0 cm (Wilcoxon signed rank test; P =0.0156 and P =0.0156) (Table 5) indicating differential velocity based on depth. Velocity measurements at 20% and 80% of water depth in the 15.0-cm depth treatment were not significantly different (Wilcoxon signed rank test; P =0.0781; Table 5). Greatest water velocities were consistently measured at 80% of water depth. The location of fastest flows within the experimental tank was influenced the by the direction of outflow from the internally located water pump.

Drift rates were affected by specific gravity, depth, and the combination of treatments (Table 6). Drift rate comparisons between specific gravity treatments within the 15.0-cm depth treatment were not significantly different (Wilcoxon rank sum test; P

=0.0880) (Table 7). Significance of depth treatments were most likely the result of increased interaction with the tank bottom due to limited movement, as only drift rates of the 15.0-cm depth treatment differed among depth treatments (ANOVA; df = 2; F = 25.7; $\underline{P} < 0.0001$) (Table 8). Final analysis did not include the 15.0-cm depth treatment due to the lack of vertical differentiation in velocity measures and insignificant differences in drift rate between specific gravity treatments.

Final evaluation of treatment effects in travel position trials indicated drift rates were affected by specific gravity and the combination of specific gravity and depth (ANOVA; df =1; F = 11.36; $\underline{P}$ =0.0009 and ANOVA; df = 1; F = 5.84; $\underline{P}$ =0.0164) (Table 9). Specific gravity alone explained the majority of the variance. Significant interaction of specific gravity and depth treatments suggested that gelatin bead contact with the tank bottom was increased at shallower depths slowing drift. Mean drift rates of gelatin beads in 4.0‰ salinity treatment were greater than those of the 0.0‰ treatment at 126% and 120%, respectively. Drift rate differences indicated that gelatin beads of greater density traveled lowest in the tank where the highest velocity water occurred. Drift rates were not significantly different between depth treatments of 28.0 cm and 40.0 cm (ANOVA; df = 1; F = 3.17; $\underline{P}$ =0.0764) (Table 9).

Drift rates of gelatin beads in travel position trials ranged from 85.7% to 171.7% of mean water velocity. Drift rates over 100% indicated gelatin beads most likely traveled within the fastest current. Extreme drift rates also indicated a potential for inaccuracy of water velocity measures. Inaccurate water velocity measures might have occurred because of water pump function. Water velocity was not uniform around the experimental tank. Water velocities were fastest at the location of the water pump.

Water velocities were measured directly opposite the water pump and may not have accurately accounted for high velocities directly at the pump. However, standardization of water velocity measurement methodology should have maintained precision between measured drift rates and allowed comparison of treatment effects.

Measured drift rates varied up to 50% across treatments. Inconsistency in drift rates indicated the possibility of additional variability in back calculations of spawning sites based on egg development, water velocity, and drift rate as in Chapter II. Measured drift rates were greater than drift rates determined during releases of gelatin beads in actual river conditions (Chapter II). Differences were most likely in part a result of the consistent nature of the experimental tank.

Vertical travel position trials indicated gelatin beads of greater specific gravity travel lower in the experimental tank where the fastest water velocities occurred. Striped bass eggs measured greater in specific gravity than gelatin beads used in striped bass egg sampling efficiency estimation. Therefore, gelatin beads used in striped bass egg sampling efficiency estimates likely traveled higher in the water column on average than striped bass eggs. Given these results, efficiency estimates were potentially overestimated. This also suggested that Red River efficiency measures might have been less accurate than those for the Washita River. Washita River striped bass egg specific gravities were less than those of the Red River. Although this investigation indicated gelatin beads might overestimate efficiency, it was not possible to define the magnitude of such an overestimate.

Investigations of traveled depth were limited by the use of only gelatin beads differing by density. Differences between gelatin beads and striped bass egg went

beyond density. Diameter is perhaps the most obvious difference not addressed by use of gelatin beads alone. It was expected that diameter and subsequent surface area were positively correlated to buoyancy. Therefore, diameter differences would have increased the potential for variable travel positioning. In addition, differences in river salinity levels were not addressed. Salinity levels were consistently greater in the Red River from 2001 to 2004, even during high flow conditions (Chapter II). Increased salinity and subsequent water density most likely increased the buoyancy of gelatin beads used in efficiency estimates.

Laboratory tank experiments provided a method for evaluating the effects of striped bass egg and bead differences in drift rate and depth of travel. However, the tank environment was uniform in comparison to river conditions and may not completely represent a natural river system. Never the less, in the consistency of the tank environment, striped bass egg and gelatin bead position in the water column was not constant. Eggs and gelatin beads traveled at all depths as they circled the tank demonstrating a random pattern drift that most likely occurred under natural conditions.

The experimental tank not only represented a consistent environment, but also limited the distance at which investigations were run. Short distance potentially biased results of both vertical travel position trials and drift rate comparisons. Small differences in drift rate that were not evident over short distances might have been magnified considerably over longer distances such as those experienced under actual river conditions. Drift comparisons of gelatin beads and striped bass eggs of the Washita River were not different, indicating that neither specific gravity nor diameter created significant drift differences. The apparent insignificant effects of physical differences in

drift comparisons was in contrast to drift depth investigations and might be directly related to the effect of short drift distances in tank trials. In addition, shallow tank depths used in the 2003 drift comparisons might have limited differentiation of water velocities and the potential for specific gravity or diameter differences to noticeably effect buoyancy and subsequent drift rate. Lack of differential water velocity at shallow tank depth was demonstrated in drift depth investigations.

The information provided in this investigation indicated the potential inaccuracy of gelatin beads as striped bass egg surrogates in the Red and Washita Rivers. Despite the potential inaccuracy of gelatin beads as striped bass egg surrogates, gelatin beads were considered a valuable tool for striped bass egg sampling efficiency investigations. From a practical perspective, my investigations suggested gelatin beads and striped bass eggs were at least loosely tied by physical characteristics and drift rates. Gelatin beads were small in diameter with a specific gravity slightly greater than 1.0, indicating their semi-buoyant nature. Even if gelatin beads only loosely approximated striped bass eggs in efficiency investigations (Chapter II), they would have provided insight on patterns of sampling efficiency and allowed for comparability between rivers.

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Table 1. Gelatin bead (orange and yellow) and Red and Washita egg diameters (mm). Gelatin bead (orange and yellow) and Red and Washita egg specific gravities. Significant differences in nonparametric statistics were assumed to represent differences in mean values. N=total tested eggs or gelatin beads, CV=Coefficient of Variation. Mean ranks with different superscripts were significantly different (Kruskal-Wallis One-Way Nonparametric ANOVA; $P \leq 0.05$).

	N	MIN	MAX	MEDIAN	MEAN RANK	MEAN	CV
			DIAMETER				
ORANGE BEADS	90	4.28	7.36	4.95	475.1[a]	5.04	11.03
YELLOW BEADS	90	4.09	6.33	4.81	457.9[a]	4.87	8.53
WASHITA EGGS	188	1.40	1.92	1.66	259.6[b]	1.66	6.83
RED EGGS	188	1.26	1.75	1.45	117.4[c]	1.48	6.82
			SPECIFIC GRAVITY				
ORANGE BEADS	6	1.0012	1.0029	1.0013	9.17[a]	1.0017	0.0667
YELLOW BEADS	9	1.0013	1.0030	1.0017	6.25[a]	1.0018	0.0496
WASHITA EGGS	15	1.0043	1.0088	1.0065	24.00[b]	1.0067	0.1201
RED EGGS	15	1.0043	1.0128	1.0117	37.00[c]	1.0111	0.2039

Table 2. Experimental striped bass egg and gelatin bead drift times (s) for trials conducted in 2003. Means represent time (s) taken to travel one circumference of the experimental tank. Significant differences in nonparametric statistics were assumed to represent differences in mean values. N=total tested eggs or gelatin beads, CV=Coefficient of Variation. Mean ranks with different superscripts were significantly different (Kruskal-Wallis one-way nonparametric ANOVA; $P \leq 0.05$).

	N	MIN	MAX	MEDIAN	MEAN	MEAN RANK	CV
GELATIN BEADS	18	9.50	12.28	11.51	11.21	55.9^{a}	7.94
WASHITA EGGS	18	8.88	13.32	11.19	11.18	53.3^{ab}	11.45
HATCHERY EGGS	18	8.67	13.56	9.99	10.18	32.5^{b}	11.79
EGGS COMBINED	36	8.67	13.56	10.38	10.68	42.9^{ab}	12.40

Table 3. Striped bass egg and gelatin bead mean drift times (s) for eggs collected in the Washita River, 2004. Means represent time (s) taken to travel one circumference of the experimental tank. N=total tested eggs or gelatin beads, CV=Coefficient of Variation. Mean ranks with different superscripts were significantly different (two sample t-test; $P \leq 0.05$).

	N	MIN	MAX	MEDIAN	MEAN	CV
EGGS	25	8.42	15.27	11.04	11.08^{a}	12.45
GELATIN BEADS	25	9.58	13.44	10.95	11.29^{a}	9.98

Table 4. Drift rate (%) of gelatin beads by color across all treatments. N = number gelatin beads tested, CV= coefficient of variation. Significant differences in nonparametric statistics were assumed to represent differences in mean values. Mean ranks with different superscripts were significantly different (Wilcoxon rank sum test; P $\leq$0.05).

	N	MIN	MAX	MEDIAN	MEAN	MEAN RANK	CV
ORANGE	180	90	171	120	120	184.9[a]	12.83
YELLOW	180	86	172	119	118	176.1[a]	13.47

Table 5. Water velocity (m/s) measures of 20% and 80% tank depth for three depth treatments. Significant differences in nonparametric statistics were assumed to represent differences in mean values. N = number gelatin beads tested, CV= coefficient of variation. Mean values at each depth with different superscripts were significantly different (Wilcoxon signed rank test; $P \leq 0.05$).

TRIAL (cm)	DEPTH %	N	MIN	MAX	MEDIAN	MEAN	CV
15.0	20	6	0.16	0.19	0.19	0.18^{a}	8.09
	80	6	0.18	0.22	0.18	0.19^{a}	10.25
28.0	20	6	0.14	0.20	0.15	0.16^{b}	18.91
	80	6	0.16	0.27	0.16	0.20^{c}	29.52
41.0	20	6	0.14	0.18	0.17	0.17^{d}	8.47
	80	6	0.16	0.21	0.19	0.19^{e}	10.19

Table 6. Evaluation of treatment effects on drift rate from vertical travel position trials. Specific gravity (S.G.), depth, and interaction variables (two-way ANOVA $P \leq 0.05$). Results based on all depth treatments.

SOURCE	DF	SS	MS	F	Pr > F
S.G.	1	0.281	0.281	13.59	0.0003
DEPTH	2	1.062	0.531	25.72	<0.0001
INTERACT	2	0.131	0.065	3.16	0.0436

Table 7. Drift rate (%) compared between specific gravity treatments of the 15.0 cm depth treatment. Significant differences in nonparametric statistics were assumed to represent differences in mean values. S.G. = specific gravity, N = number gelatin beads tested, CV= coefficient of variation. Mean values with different superscripts were significantly different (Wilcoxon rank sum test; $P \leq 0.05$).

S.G.	N	MIN	MAX	MEDIAN	MEAN	MEAN RANK	CV
0.0‰	60	88	153	109	109	55.1[a]	13.08
4.0‰	60	86	145	112	114	65.9[a]	12.47

Table 8. Drift rate (%) within depth treatments. N = number gelatin beads tested, CV= coefficient of variation. Mean values with different superscripts were significantly different (ANOVA; $P \leq 0.05$).

N	MIN	MAX	MEDIAN	MEAN	CV
			15 cm		
120	86	153	111	112^{a}	12.85
			28 cm		
120	96	148	121	121^{b}	9.61
			41 cm		
120	86	172	122	124^{b}	14.12

Table 9. Evaluation of treatment effects on drift rate from vertical travel positioning trials. Specific gravity (S.G.), depth, and interaction variables (two-way ANOVA). Results do not include 15.0 cm depth treatment.

SOURCE	DF	SS	MS	F	Pr > F
S.G.	1	0.237	0.237	11.36	0.0009
DEPTH	1	0.066	0.066	3.17	0.0764
INTERACT	1	0.122	0.122	5.84	0.0164

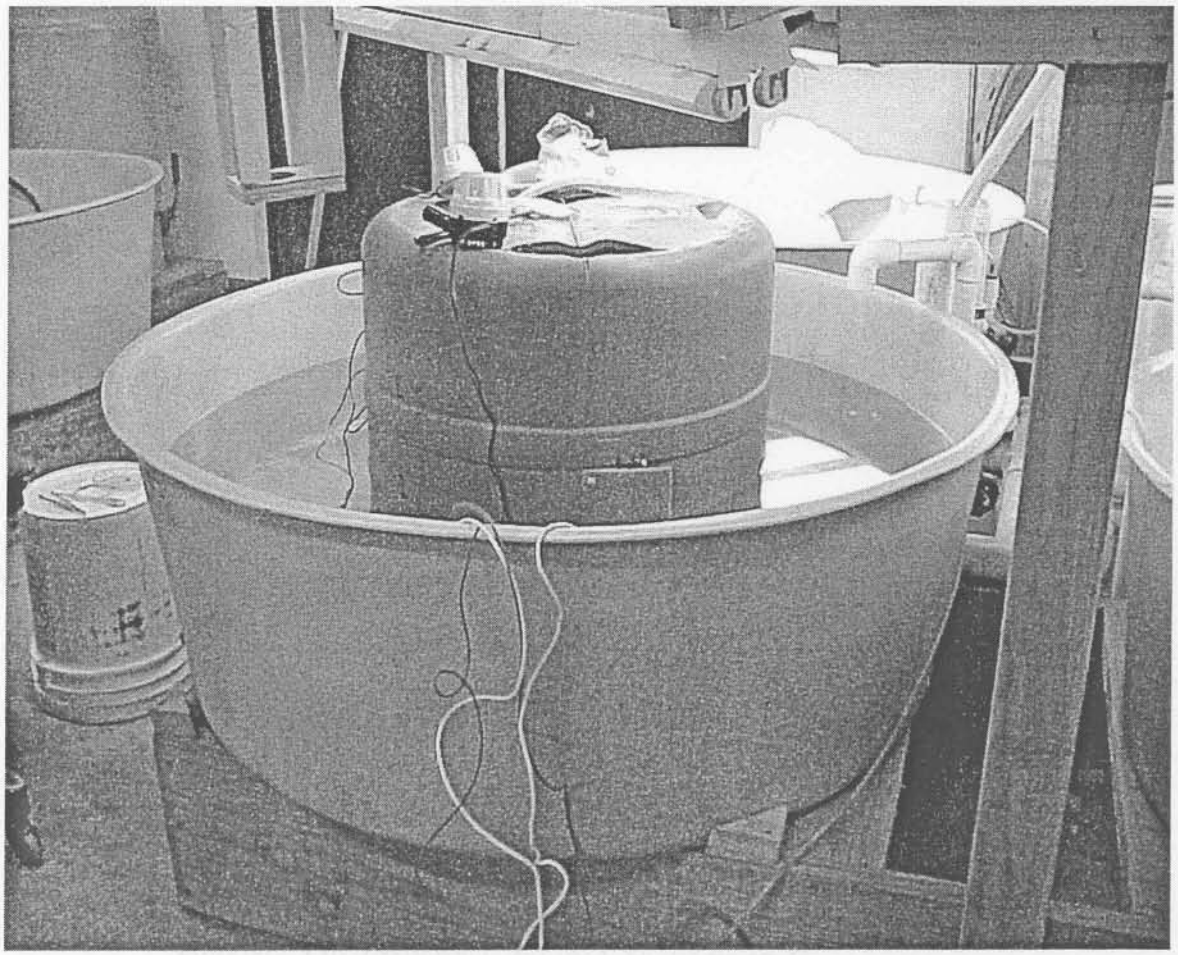

Figure 1. Experimental tank used in egg-bead investigations.

CHAPTER II

ESTIMATION OF STRIPED BASS *MORONE SAXATILIS* EGG SAMPLING EFFICIENCY FOR USE IN EGG COLLECTION COMPARISONS

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Abstract – Striped bass eggs were collected to determine the relative reproductive contributions of the Red and Washita Rivers as striped bass spawning tributaries of Lake Texoma, Oklahoma-Texas. In order to compare striped bass egg production between rivers of dissimilar channels, understanding striped bass egg sampling efficiency was necessary. Identification of striped bass spawning locations was also important for understanding reproduction of striped bass in this system. Objectives of this research were to: 1) estimate sampling efficiency of striped bass eggs in the Red and Washita Rivers over variable flow conditions; 2) compare egg production between the Red and Washita Rivers; 3) estimate striped bass egg drift rates for use in determining spawning locations; and 4) estimate striped bass spawning locations in the Red and Washita Rivers. Known numbers of gelatin beads as surrogate striped bass eggs, were released above sample sites and recaptured to estimate striped bass egg sampling efficiency. Striped bass eggs collections were adjusted by efficiencies for comparison of relative egg production between rivers. Red River sampling efficiencies ranged from 0.336% to 0.001%. Sampling efficiency in the Washita River ranged from 0.287% to 0.032%. Efficiency-corrected egg collections suggested that the Washita River played a larger role in Lake Texoma striped bass egg production. Striped bass egg drift rates were estimated from gelatin bead drift during efficiency estimates. Mean drift rates of 108% and 71% were estimated in the Red and Washita Rivers, respectively. Striped bass spawning locations estimated by development, water temperature, estimated drift rate, and water velocity occurred from 80 to 119 km and 130 to 149 km up river of Lake Texoma in the Red River and from 50 to 109 km up river of Lake Texoma in the Washita River.

INTRODUCTION

Lake Texoma, a nationally recognized striped bass *Morone saxatilis* fishery, is a destination for anglers nation wide (Schorr et al. 1995). The related income from Lake Texoma to the surrounding economy is significant. In 1990, an estimated $26.5 million is spent on striped bass fishing and related services at Lake Texoma annually (Schorr et al. 1995), making this fishery potentially the most valuable in Oklahoma. Mauck (1993), reported over 60% of the fishing effort on Lake Texoma is devoted to striped bass.

The striped bass is an anadromous species native to the Atlantic and Gulf coasts of North America. In the late 1870's, striped bass from New Jersey were introduced to the Pacific coast in the San Francisco Bay area (Talbot 1966). The Pacific population became sufficiently abundant as far north as the Oregon coast to support a commercial fishery in that area by the 1930's (Wydoski and Whitney 1979). It was first discovered that striped bass could complete their life cycle in inland waters in the Santee-Cooper system, South Carolina where an anadromous population of striped bass was trapped and subsequently reproduced during impoundment of Lakes Marion and Moultrie (Bailey 1975; Jarman and Harper 1970; Scruggs 1957). Following this discovery, striped bass were stocked in over 450 inland reservoirs throughout the United States (Stevens 1984). Striped bass were initially introduced as both a biological control, primarily of clupeid populations, and to create sport-fishing opportunities (Axon and Whitehurst 1985; Combs and Peltz 1982; Jarman and Harper 1970; Mauck 1993).

Most inland populations require annual stocking to maintain fishable numbers (Cheek et al. 1985). Only about 10 naturally reproducing inland populations of striped bass throughout the country have been established from introductions, of which two

Keystone Lake and Lake Texoma, are located in Oklahoma (Mauck 1993; Mensinger 1971; Shelton 1996; Stevens 1984). The Oklahoma Department of Wildlife Conservation stocked striped bass into Lake Texoma from 1965 to 1974. Reproduction was first documented in 1973 and has been subsequently verified annually (Mauck 1993).

Striped bass spawning generally occurs in swift, turbulent current in association with rocky substrate (Albrecht 1964; Kornegay and Humphries 1976), but other artificial substrates such as submerged pilings or car bodies can create sufficient turbulence for spawning (Combs 1980). Environmental conditions are important factors in the timing and success of spawning. Spawning is initiated at temperatures ranging of 13 to 18 °C. Spawning activity culminates at temperatures ranging from 17.5 to 26.5 °C (Combs 1980; Davin et al. 2001; Kornegay and Humphries 1976; Rathjen and Miller 1957). Incubation of striped bass eggs is influenced by temperature. Striped bass eggs hatch in approximately 48 hrs at about 17 °C (Albrecht 1964).

Physical characteristics of striped bass eggs are important in their survival. Striped bass produce spherical, non-adhesive, pelagic egg that requires moving water for buoyancy (Mansueti 1958). Spawned striped bass eggs swell during the water hardening process (Albrecht 1964; Combs 1980; Mansueti 1958). Striped bas egg diameter is related to water salinity (Mansueti 1958). Salinity influences striped bass egg chorion expansion and contraction through osmosis. Swollen striped bass eggs have a specific gravity slightly greater than 1.0 (Albrecht 1964; Hurley 1991) enabling them to be buoyed in flowing water. Specific gravity of striped bass eggs is negatively related to diameter, indicating that larger eggs have potentially greater buoyancy (Albrect 1964).

Embryo and larval survival is influenced by water salinity. Embryos typically can withstand higher salinities than larvae. Winger and Lasier (1994) reported that embryo survival is significantly reduced at salinity levels above 18‰ while larval survival is impaired at levels of 12 to 15‰. However, salinities of 1 to 10‰ may actually increase larval survival (Albrecht 1964; Bonn et al. 1976; Kane et al. 1990; Winger and Lasier 1994).

Water flow also influences survival of striped bass embryo and larvae (Albrecht 1964; Bulak et al. 1997). Semi-buoyant striped bass eggs that settle out of suspension are susceptible to smothering by sediment. Current velocities from 0.03 to 0.31 m/s have been reported as necessary for maintaining buoyancy of striped bass eggs (Albrecht 1964; Hurley 1991). Water flow in combination with temperature is important for delivery of the developing egg to suitable nursery habitat near the time of hatching (Bulak et al. 1997).

Striped bass spawning has been documented in both major tributaries of Lake Texoma, but the relative contribution of each tributary to recruitment is poorly understood (Baker 2003; Mauck 1993). A recently proposed water diversion and salinity reduction project potentially threatens Red River Striped bass recruitment (Jeff Boxrucker, Senior Biologist, Oklahoma Department of Wildlife Conservation, personal communication). Proposed actions are expected to effect water salinity and river flows. One approach to better understanding the Lake Texoma population and the potential threats of proposed changes to the Red River is to define the importance of its two major tributaries, the Red and Washita Rivers, and their role in supporting striped bass reproduction. Initial data under Oklahoma Federal Aid Grant F-50-R, Project 14,

suggests that a greater proportion of Lake Texoma striped bass egg production occurs in the Washita River (Baker 2003). However, striped bass egg sampling efficiencies may differ between rivers, making initial egg collections misleading.

Morphological variability associated with river hydrology indicated the potential for differences in striped bass egg sampling efficiency in the Red and Washita Rivers. Sampling efficiency was defined as the proportion of total striped bass eggs passing a sample site during the sample period that are captured. The Red River was observed to have a wide, shallow channel, which was expected to have a negative effect on sampling efficiency associated with rising discharge (personal observation by the investigator). Theoretically, as wetted channel width expanded with increased water volume it would became more difficult to capture drifting striped bass eggs. The Washita River was defined by a narrow confined channel (personal observation by the investigator). The dramatic changes in channel width associated with variable discharge due to channel morphology that occur in the Red River do not occur in the Washita River (personal observation by the investigator). Therefore, sampling efficiency was expected to be greatest in the Washita River.

Striped bass egg production has been estimated in other systems by extrapolating sampled egg density in relation to river volume (Davin et al. (2001); Hurley (1991); Kornegay and Humphreys 1976). By using this method, striped bass eggs were assumed to distribute evenly across the river channel, an assumption that might not always be correct. Because channel morphology differed considerably between the Red and Washita Rivers, striped bass eggs may be distributed differently. Therefore, estimation

of sampling efficiency for each river was necessary for comparison of egg production between rivers.

Reinert et al. (2004), demonstrated surrogate striped bass eggs, similar to striped bass eggs in size and specific gravity, could be used to estimate striped bass egg sampling efficiency in the Savannah River system. Reinert et al. (2004) used gelatin beads as surrogate striped bass eggs in release/recapture efforts to determine sampling efficiency. Gelatin bead trials conducted in the Savannah River, Georgia, provided evidence of previously unsuspected bias in sampling efficiency in that system due to channel morphology and hydrology.

In an effort to better understand the reproductive dynamics of Lake Texoma striped bass and define the relative contribution of the Red and Washita Rivers in striped bass egg production the objectives of this research were to: 1) estimate sampling efficiency for striped bass eggs in the Red and Washita Rivers over variable flow conditions; 2) compare egg production between the Red and Washita Rivers; 3) estimate striped bass egg drift rates for use in back calculation of spawning sites; 4) and estimate striped bass spawning locations in the Red and Washita Rivers. Release and recapture of gelatin beads was used to estimate efficiency in each of the two rivers. Results were applicable to striped bass egg collections for use in determining comparable relative estimates of eggs passing during 10-min sampling efforts. Drift rates were used to determine areas of striped bass spawning. Defining spawning areas was important for better understanding the reproductive requirements of striped bass in this system.

STUDY AREA

In 1944, the U.S. Corp of Engineers impounded the Red River approximately 7.4 km below its confluence with the Washita River with the construction of Denison Dam to form 36,000-hectare Lake Texoma (Mauck 1993). Lake Texoma forms a portion of the border between Oklahoma and Texas. The two main tributaries, the Red and Washita rivers, drain a large portion of western Oklahoma and northern Texas. Lake Texoma is a multipurpose reservoir and known for its fishing opportunities, especially for striped bass (Mauck 1993; Schorr et al. 1995).

METHODS

SAMPLING EFFICIENCY

To allow for accurate comparison of striped bass eggs collected in the Red and Washita Rivers, I estimated striped bass egg sampling efficiency in both rivers. Sampling efficiency was defined as the percentage of striped bass eggs captured from the total number of striped bass eggs passing a given sample site during a 10-min sample effort. Striped bass egg sampling efficiency was estimated by releasing and recapturing known numbers of striped bass egg surrogates in both rivers.

I used gelatin beads (Technology Flavors and Fragrances, INC., Amityville, New York) as striped bass egg surrogates. Orange and yellow gelatin beads, similar to striped bass eggs in size and specific gravity, were used as surrogate striped bass eggs. Although gelatin beads were considered adequately similar to striped bass eggs for use in sampling efficiency estimation, gelatin beads were larger and lower in specific gravity than striped bass eggs of the Red and Washita Rivers (Chapter I). Differences in physical

characteristics indicated gelatin beads are more buoyant than striped bass eggs. I suggested in Chapter I that gelatin beads which are more buoyant than striped bass eggs may be more susceptible to capture under current sampling methodology than striped bass eggs, thus potentially over-estimating striped bass egg sampling efficiency.

Reinert et al. (2004) indicated gelatin beads taken directly from the sucrose solution in which they were transported and stored ranged in specific gravity (± SD) from 1.0067 ± 0.0004 to 1.0324 ± 0.0029. Reinert et al. (2004) demonstrated that specific gravity of gelatin beads could be reduced to a level more closely resembling the specific gravity of striped bass eggs by washing in water. Therefore, to approximate the specific gravity of striped bass eggs, I washed gelatin beads prior to use in striped bass egg sampling efficiency estimation. Gelatin beads were washed using non-chlorinated water. Wash water salinity was 0.4‰. Washing included straining gelatin beads from the sucrose packing solution in which they were shipped and stored, placing gelatin beads in 20-L buckets, and flushing each bucket with water from the bottom up until gelatin beads exhibited a noticeable increase in buoyancy (~ 2 to 3 h). Initially, gelatin beads in 20-L buckets were soaked and rinsed several times with water over a period 2 to 3 days. The flushing method was developed by trial and error to increase the rate at which gelatin beads could be prepared for use. Gelatin beads were stored post-wash in non-chlorinated water for at least 24 hours prior to use.

I determined the total number of gelatin beads released during striped bass egg sampling efficiency estimation by weight. The number of gelatin beads per gram was estimated by weight of five 50-gelatin bead samples and expanded to kilograms. Buckets

used for storing gelatin beads prior to use were filled with 250,000 gelatin beads, equal to either 9.6 kg of orange gelatin beads or 10.1 kg of yellow gelatin beads.

I conducted preliminary gelatin bead investigations during which gelatin beads were released at suspected spawning locations. Gelatin beads were followed as they drifted downstream. Gelatin beads were recaptured when passing sample sites at several locations downstream of the release point over a period of approximately 48 hours. It was evident from the collections that gelatin beads spread along the river channel as distance from the release sites increased. Gelatin bead recaptures declined and gelatin beads were captured for longer periods as distance from the release point increased. To account for change in capture rates over distance during striped bass efficiency estimation, I standardized the distance from recapture sites used in efficiency estimation and gelatin bead release sites up river. A standard distance of 1.5 km was chosen because it represented a distance at which the total of released gelatin beads could be sampled within several 10-min efforts yet it allowed enough distance that ideally gelatin beads were influenced by river currents in a fashion similar to striped bass eggs drifting down river.

I estimated striped bass sampling efficiency at three sites on each river. Sites were identical to those used as sample sites for annual egg collections. Sample sites were chosen in 2001 (Baker 2003). Sites were selected to allow for sampling of striped bass eggs throughout the lower reaches of each river and based on availability. Sites were located at river kilometer 127.4, 83.3, and 46.4 on the Red River and 90.5, 54.8, and 42.0 on the Washita River (Figure 1). Distances were measured up river from Lake Texoma (identified as more lentic conditions) using the Digital Atlas of Oklahoma (Rea and

Becker 1997). Sites from here forward were denoted by the first letter of the rivers name and numbered from 1 to 3, with 1 indicating the uppermost site.

I conducted striped bass egg efficiency estimates by releasing 250,000 orange or yellow gelatin beads 1.5 km up river of an individual sample site. Distance above sample sites was measured using a Garmin GPS 12 XL (GARMIN, Olathe, Kansas). Gelatin beads were dumped from a boat evenly across the river channel. Return travel to recapture sites by boat typically took 5 min to 10 min. Gelatin beads arrived at sample sites from 15 min to over and hour following release. I estimated the time of gelatin bead arrival based on water velocity. Recapture efforts began 5 min to 10 min prior to estimated arrival of gelatin beads. Average depth (m) across the river channel at sample sites was measured on a limited basis in combination with efficiency estimates.

I recaptured gelatin beads using two conical plankton nets set just below the waters surface at sample sites. Conical plankton nets 50 cm in diameter and 150 cm in length made of 500-micron mesh were identical to the net used in striped bass egg sampling efforts associated with this investigation and by Baker (2003). Filtered volume of samples was measured using a General Oceanics flow meter (General Oceanics Inc., Miami, Florida) attached in the mouth of the plankton net. Nets were set in primary areas of flow from either bridges or a boat. I used a boat from which two conical plankton nets could be set away from flow disturbance created by the boat itself only at sample sites R2 and R3 on the Red River (Figure 2). A boat was necessary because sample sites with bridges were limited on the Red River. Distance between nets was limited when fished from the boat. Nets fished from the boat may have functioned more as paired samples.

I recaptured gelatin beads in consecutive 10-min units of effort until it was determined that gelatin beads had passed the site as evident by lack of gelatin beads in samples. However, consecutive samples were separated by the time required to pull the net and replace the sample cup, typically one to five minutes. The total proportion of gelatin beads passing during non-sampling periods was unaccounted for and likely reduced the total number of gelatin beads from which collections were made. Each net was considered an individual sample. I sorted and counted gelatin beads from collected samples in the laboratory.

I calculated striped bass sampling efficiency per unit effort (CPUE = % efficiency/10-min sample) as the number of gelatin beads recaptured divided by the proportion of total beads released passing during a 10-min sample. The proportion of total released gelatin beads passing during a 10-min sample was defined by the proportion of total recaptures made in each sample. I assumed that greater captures resulted from greater numbers of gelatin beads present during a sample. This method defined a single efficiency for all samples in a trial equal to the total number of captured beads divided by the total number of released beads.

I accounted for variation in sampling efficiency due to variable discharge by conducting gelatin bead trials across a range of discharge levels (Tables 1 and 2). Discharge ranges were unique to each river and represented river conditions in which sampling was physically possible, determined from striped bass egg sampling experiences. Discharge ranges were divided equally into three categories (low, medium, and high) to describe the range of efficiency estimates. Real time discharge measures were obtained from the U.S. Geological Survey's (USGS) Water Resources of Oklahoma

web page (http://waterdata.usgs.gov). USGS gauging stations from which discharge measures were taken included #07315500 located near Terral, Oklahoma and #07316000 located near Gainesville, Texas on the Red River and #07331000 located near Dickson, Oklahoma on the Washita River. Although, ideally striped bass egg sampling efficiency estimates would have equally represented all discharge categories, low water years throughout the region and subsequent low flow limited estimates at medium and high flows. Efficiencies from individual sample sites were combined due to the limited number of trials at each site and because efficiencies did not appear to differ considerably between sites.

In an effort to define the factors that effect striped bass egg sampling efficiency I described the relationship between the dependant variable efficiency and independent variables discharge, sampled water volume, and depth of sampled area using multiple regression procedures ($P \leq 0.05$) (SAS, version 8.1, PROC REG). Efficiency was modeled by independent variables in all possible combinations.

I evaluated the potential for variability in efficiency estimates due to net placement and distribution of drifting gelatin beads by comparing efficiency estimates from the two plankton nets set to collect gelatin beads during each efficiency trial (paired t-test; $P \leq 0.05$). Efficiencies from net pairs were labeled as A and B net efficiencies for comparisons

STRIPED BASS EGG COLLECTIONS

Striped bass eggs were collected from early April until approximately the second week of May in 2001, 2002, 2003, and 2004. Striped bass egg collection data from 2001

was taken from Baker (2003). Striped bass eggs were collected from the Red and Washita Rivers using one conical plankton net 50-cm in diameter, 150 cm in length, made of 500-micron mesh from bridges and boats (as determined by site availability). Nets were fished just below the surface at mid-river channel (thalweg) as described by Kornegay and Humphries (1976). The amount of water filtered for each sample was measured using a General Oceanics flow meter (General Oceanics Inc., Miami, Florida) attached in the mouth of the plankton net. Striped bass eggs were collected at three locations on each river previously described. Sample locations were maintained from year to year. Collections were taken three times weekly at each sampling location during daylight hours with the Red and Washita Rivers sampled on alternate days. Collections were 10 min in duration in 2002 through 2004 and 15 min in 2001 unless the net clogged. Samples not equal to 10 min were corrected by the proportion of eggs captured in the sampled time. Sampling was continued until no eggs were collected. All samples were preserved in 7% unbuffered formalin containing Sudan IV and eosin B pigments (Klinger and Van Den Avyle 1993). Pigments were added to the formalin to make striped bass eggs more visible and ease separation from other eggs, larval fish, and miscellaneous debris. Photos of striped bass eggs by Hassler et al. (1981) and Baker (2003) were used to aide identification of striped bass eggs by providing a reference of key characteristics. Eggs were directly counted in the laboratory.

Temperature, conductivity, and salinity measures were taken during egg collections. Measurements were made with an ORION model 105 conductivity/salinity meter (Orion Research Inc., Beverly, Massachusetts).

I adjusted striped bass egg collections made in 2001, 2002, 2003, and 2004 by striped bass egg sampling efficiency estimates. Egg collections were adjusted by dividing daily egg captures by efficiency percentages associate with the discharge category at which eggs were collected. I substituted missing egg collections for days when weather, river conditions, or sampling schedule did not allow sampling with the mean number of eggs collected per sample in that week on other days. Efficiency adjusted egg collections for individual sample sites were summed by day. Egg collections were not normally distributed (Shapiro-Wilks test; $P \leq 0.05$). Log_{10}-transformation failed to adequately normalize data. Consequently, I used a Wilcoxon Rank Sum test ($P \leq 0.05$) to compare differences between rivers within years and a Kruskal-Wallis nonparametric one-way ANOVA ($P \leq 0.05$) to compare differences between years by river and between years for combined rivers. A Kruskal-Wallis nonparametric all-pairwise comparison test ($P \leq 0.05$) was used to evaluate significant findings.

A relatively small number of striped bass egg samples were collected in each river in all years. Sample size was limited by sampling protocol and spawning period length. Striped bass egg collection comparisons were unable to detect large differences in striped bass egg collection annual means up to 300%. Sample size was suspected to reduce test power. Chittenden (2002) indicated small sample size generally results in wide confidence intervals and high probability of type II error when H_O is "accepted". Toft and Shea (1983) indicated that increasing the probability of a type I by increasing α was an acceptable method for reducing the probability of a type II error. Therefore, I considered low power and small sample sizes plausible reasons for evaluating striped

bass egg collections at $\alpha > 0.05$ (Chittenden 2002; Toft and Shea 1983). I considered $P \leq 0.05$ to determine significance and $P \leq 0.10$ to detect differences considered to be of biological interest.

In addition, I compared egg collections during peak egg production periods only. Striped bass egg production in the Red and Washita Rivers primarily occurred in peak periods during all years sampled. I isolated peak striped bass egg collections by considering only egg collections ten percent of the largest egg collection or greater for a given year. No more than 10% of the total annual striped bass eggs collected were eliminated in any year utilizing this method. Sample size was reduced considerably. However, the variance of data sets was also reduced. Efficiency adjusted egg collections for individual sample sites were summed by day. Log_{10}-transformation homogenized variance and satisfactorily normalized data. I used a two sample t-test ($P \leq 0.05$) to compare striped bass egg collections by river within years. I used a one-way ANOVA ($P \leq 0.05$) to compare striped bass egg collections by year within rivers and a Tukey HSD all-pairwise comparison test ($P \leq 0.05$) to define differences of significant findings. Combined river data compared between years were not normally distributed (Shapiro-Wilks test; $P \leq 0.05$). Log_{10}-transformation failed to normalize data. Therefore, I used a Kruskal-Wallis nonparametric one-way ANOVA ($P \leq 0.05$) to compare differences between years for combined rivers. A Kruskal-Wallis nonparametric all-pairwise comparisons test (≤ 0.05) was used to evaluate significant findings.

STRIPED BASS EGG DRIFT RATE

I estimated striped bass egg drift rates as a percentage of water velocity by timing travel of gelatin beads released during efficiency trials. Drift rates of striped bass eggs were used in identification of spawning sites through back calculation of egg drift. Gelatin bead drift rate (m/s) was determined as the time required to travel the 1.5 km between the release site and associated sample site during striped bass egg sampling efficiency estimation. Gelatin bead recaptures associated with striped bass egg sampling efficiency estimation consisted of multiple 10-min samples. Therefore, I calculated average drift rate as a weighted average of the multiple samples. Averages were weighted by the proportion of total gelatin beads captured during a given sample. River velocity was estimated using daily average discharge data from USGS gauging stations #07315500 located near Terral, Oklahoma and #07316000 located near Gainesville, Texas on the Red River and #07331000 located near Dickson, Oklahoma on the Washita River. Baker (2003) modeled the relationship between velocity and discharge levels on the Red and Washita River using historical USGS data from which average daily velocity was estimated based on current average daily discharges. Data were obtained at the U.S. Geological Survey's (USGS) "Water Resources of Oklahoma" web page (http://waterdata.usgs.gov). Drift rate was divided by water velocity and described as a percentage of water velocity.

Drift rates were also determined as a percentage of water velocity measured using a Model 2000 Flow-Mate digital flow meter (Marsh-McBirney, INC., Frederick, Maryland). Measures of velocity were taken every 0.5 km within the 1.5 km sample zone, including sample site locations. Measures were taken across the river channel at

three or four equal intervals, depending on total channel width, at each 0.5 km location. Digital velocity measures were not collected during all trials. Depth measurements were taken in association with velocity measures to determine the proper measurement location. At depths of 0.75 m or less, one measurement was taken at 60% of depth. At depths greater than 0.75 m, the average of two measures taken at 20% and 80% of depth was used. On occasions when water was too deep for available equipment, measures were taken at 0.25 m. Drift rate was divided by water velocity and described as a percentage of water velocity.

SPAWNING SITE ESTIMATION

I determined egg age (hours) for viable striped bass eggs collected in 2002, 2003, and 2004 based on developmental stage and temperature. Egg age was used in identifying spawning sites based on back calculation of egg age and water velocity. Developmental staging protocol was adapted from Baker (2003). All viable (live at time of capture) eggs were staged in samples containing 50 or fewer eggs. A sub-sample of 25% of the total number or 50 eggs (whichever was greater) was otherwise staged unless that number exceeded 300, in which case 300 eggs were staged. Non-viable eggs were defined as those eggs with a characteristically opaque appearance. A nomograph by Hassler et al. (1981) was used to describe the relationship between egg stage and temperature. Only eggs collected at temperatures from 14.5 to 22.5 °C were used in aging, as the nomograph by Hassler et al. (1981) does not incorporate developmental rates outside of this temperature range.

Estimated striped bass egg drift rates and egg age were used to back calculate spawning locations. Egg age in hours multiplied by water velocity at the given collection site, accounting for actual drift rate as previously determined, allowed estimation of total distance traveled from fertilization. Spawning location of individual eggs was determined by the total distance traveled from the site at which the egg was collected.

RESULTS

SAMPLING EFFICIENCY

Efficiency trials were completed at discharge levels ranging from 15 to 569 m^3s^{-1} (n = 21) on the Red River (Table 1) and from 15 to 125 m^3s^{-1} (n =16) on the Washita River (Table 2). Fifteen of the 21 Red River trials occurred during low flow condition (10-190 m^3s^{-1}), while nine of the 16 Washita River trials occurred during low flow conditions (5-51 m^3s^{-1}). Depth ranges associated with efficiency estimates for individual sample sites and associate discharge ranges were presented in Table 6.

Red River efficiency measures ranged from 0.336% to 0.001%. Percent efficiency declined dramatically between 55 and 94 m^3s^{-1}. Although efficiency trials were organized for collection according to three discharge categories (Table 1), two distinct groups (high and low efficiency) were identifiable from resulting measures. Distinct groups were defined by those efficiencies above and below the mid-point (74.5 m^3s^{-1}) of the observed decline in efficiency data. A discrete mean efficiency from each distinct group was used to model the efficiency of egg captures. Discharge events from 15 m^3s^{-1} to 74.5 m^3s^{-1} were defined by a mean efficiency of 0.166% ± 0.032% (95% C.I.). Discharge events from 74.5 m^3s^{-1} to 569 m^3s^{-1} were defined by a mean efficiency of 0.044% ± 0.019% (95% C.I.). A and B net efficiencies were not significantly different

(paired t-test; P=0.3518) indicating limited variability due to net placement and even distribution of gelatin beads across the sampled channel (Table 3).

Washita River efficiency measures ranged from 0.287% to 0.032%. Efficiencies were described by three discharge categories (low, medium, high) (Table 2). Discrete mean efficiency values within each predetermined discharge category were used to model efficiency of egg captures. Low flow discharge events from 5 to 51 m^3s^{-1} were defined by a mean efficiency of 0.139% ± 0.026% (95% C.I.). Medium flow discharge events from 51 to 97 m^3s^{-1} were defined by a mean efficiency of 0.124% ± 0.062% (95% C.I.). High flow discharge events from 97 to 143 m^3s^{-1} were defined by a mean efficiency of 0.065% ±0.045 (95% C.I.). A and B net efficiencies were not significantly different (paired t-test; P=0.1804) indicating limited variability due to net placement and even distribution of gelatin beads across the sampled channel (Table 3).

Multiple regression analysis of Red River efficiency data (Table 4) indicated a significant relationship between discharge (m^3s^{-1}) and efficiency (ANOVA; P=0.0068). Discharge alone explained 25.0% of the variance in efficiency measures. The relationship between discharge, total volume sampled (m^3), and efficiency was significant (ANOVA; P=0.0069), but only explained an additional 0.01% of the variance. The combination of discharge and sample site depth explained an additional 12.8% (ANOVA; P=0.0027). Multiple regression analysis of Washita River efficiency data (Table 5) indicated an insignificant relationship between discharge (m^3s^{-1}) and efficiency (ANOVA; P=0.1229). The combination of discharge, total volume sampled (m^3), and efficiency was insignificant (ANOVA; P=0.2153). Sample site depth alone explained

43% of the variability in the data (ANOVA; P=0.0043). The combination of sample site depth and discharge explained an additional 23.2% (ANOVA; P=0.0005).

STRIPED BASS EGG COLLECTIONS

Striped bass eggs in 2002 were sampled from 7 April to 10 May. Red River striped bass egg collections were not conducted at sample sites R2 and R3 due to high water on 10 April and 15 April. Collections were not taken on 24, 30 April, and 1 May at all or two of the sample sites due to alternate scheduling associated with preliminary gelatin bead releases. In addition, collections were not taken on 7 May at sites R1 and R3 and on 10 May at site R3 due to river access difficulty. Due to high water, Washita River sampling was discontinued from 7 April to 15 April and on 25 April due to alternate scheduling associated with preliminary gelatin bead releases. Red River discharge during the sampling period in April and May of 2002 ranged from 21 to 530 m^3s^{-1}. Flows from 7 April to 20 April were above the 64-year average (Figure 3). Red River temperatures averaged 20.8°C (range 14.1-25.8 °C) (Appendix I). Following 21 April, flows steadily declined. Washita River discharge during the sampling period in April and May of 2002 ranged from 12 to 776 m^3s^{-1}. Flows from 7 April to 21 April were above the 64-year average (Figure 5). Washita River temperatures during the sample period averaged 20.0 °C (range 14.1-25.8°C) (Appendix II). A total of 1,296 and 4,854 striped bass eggs were collected in the Red and Washita Rivers, respectively. Egg collections averaged 0.98 and 4.30 eggs/m^3 in the Red and Washita Rivers, respectively.

Striped bass eggs in 2003 were sampled from 7 April to 10 May. Red River discharge during the sampling period in April and May of 2003 ranged from eight to 24

m^3s^{-1}. Red River flows during the sampling period were well below the 64-year average (Figure 4). Temperatures during the sample period averaged 20.5 °C (range 9.6-29.0 °C) (Appendix III). Washita River discharge during the sampling period in April and May of 2003 ranged from 10 to 41 m^3s^{-1}. Washita River flows during the sampling period were well below the 64-year average (Figure 6). Temperatures during the sample period averaged 21.1 °C (range 13.1-27.8°C) (Appendix IV). In 2003, 630 and 17,108 striped bass eggs were collected in the Red and Washita Rivers, respectively. Egg collections averaged 0.56 and 9.55 eggs/m^3 in the Red and Washita Rivers, respectively.

Striped bass eggs in 2004 were sampled from 5 April to 18 May. A sample was not collected on 5 April at site R3 due to river access difficulties. Red River discharge during the sampling period in April and May of 2004 ranged from 10 to 139 m^3s^{-1}. Red River flows during the sampling period were below the 64-year average with the exception of one peak occurring on 2 May (Figure 4). Temperatures during the sample period averaged 20.5°C (range 13.0-25.1°C) (Appendix V). Washita River discharge during the sampling period in April and May of 2004 ranged from 9 to 44 m^3s^{-1}. Washita River flows during the sampling period were well below the 64-year average (Figure 6). Temperatures during the sample period averaged 20.5 °C (range 14.1-26.0 °C) (Appendix VI). Totals of 10,347 and 22,694 striped bass eggs were collected in the Red and Washita Rivers, respectively. Egg collections averaged 2.78 and 7.84 eggs/m^3 in the Red and Washita Rivers, respectively. Peak egg production periods in all years were associated with the descending flows following peak flow conditions (Figures 7-12). Egg production peaks occurred primarily between 20 April and 30 April.

Mean daily striped bass egg collections prior to efficiency corrections were consistently greater in the Washita River in all years. However, between river differences in egg collection were significant only in 2003 (Wilcoxon rank sum test; $\underline{P}$=0.0306) (Table 7). Mean Washita River striped bass egg collections corrected by efficiency measures in 2001, 2002, 2003, and 2004 were 350%, 180%, 2900%, and 150% greater, respectively than those of the Red River for corresponding years (Table 8). However, corrected egg collections compared by river were only significantly different in 2003 at $\alpha \leq 0.05$ and $\alpha \leq 0.10$ (Wilcoxon rank sum test; $\underline{P}$=0.0244). Red River efficiency corrected striped bass egg estimates evaluated by river among years indicated that 2003 differed from 2001 and 2004 (Kruskal-Wallis one-way nonparametric ANOVA; df = 3; F = 3.10; $\underline{P}$=0.0331) (Table 9). Although significant differences were detected at $\alpha \leq 0.05$ all-pairwise comparisons indicated differences only at $\alpha \leq 0.10$. Striped bass egg collections were not different among 2001, 2002, and 2004. Washita River viable striped bass egg estimates evaluated by river among years were not different in any year even at $0.05 \leq \alpha \geq 0.10$ (Kruskal-Wallis one-way nonparametric ANOVA; df = 3; F = .20; $\underline{P}$=0.8939) (Tables 9). Striped bass egg collections combined by year and compared among years were not significantly different at $\alpha \leq 0.05$ and only marginally so at $\alpha \leq 0.10$ (Kruskal-Wallis one-way nonparametric ANOVA; df = 3; F = 2.17; $\underline{P}$=0.0946) (Table 10). All-pairwise comparisons at $\alpha \leq 0.10$ detected no differences among years for combined rivers.

Efficiency corrected striped bass egg collections isolated by peak production compared by river within years were significantly different in 2001 (two sample t-test; $\underline{P}$=0.0400) and 2003 (two sample t-test; $\underline{P}$=0.0238) (Table 11). Red River striped bass

egg collections evaluated by river among years indicated that 2003 differed from 2001 and 2004 (one-way ANOVA; df = 3; F = 5.89; P=0.0091) (Table 12). Striped bass egg collections were not different among 2001, 2002, and 2004. Washita River viable striped bass egg collections evaluated by river among years were significantly different only in 2002 (one-way ANOVA; df = 3; F = 8.78; P=0.0024) (Table 12). Differences in efficiency corrected peak striped bass egg collections combined by year and compared among years were significant (Kruskal-Wallis one-way nonparametric ANOVA; df = 3; F = 3.30; P=0.0340) (Table 13). However, all-pairwise comparisons detected no differences among years for combined rivers.

STRIPED BASS EGG DRIFT RATE

Drift rates of gelatin beads released in the Red River, based on USGS velocity estimates, ranged from 76% to 149% (n = 21) of estimated water velocity and averaged 108% ± 8% (95% C.I.). Drift rates of gelatin beads released in the Washita River based on USGS velocity estimates ranged from 49% to 98% (n = 16) of estimated water velocity with an average of 71% ± 8% (95% C.I.). Drift rate estimates based on measured flow ranged from 57 to 154% (avg. ~ 97%) and 66 to 138% (avg. ~ 98%) in the Red and Washita Rivers, respectively. Due to relatively few measures on which measured flow estimates were based and limitations of equipment at moderate and high flows, drift estimates based on USGS velocity estimates were used in spawning site back calculations. Drift rates above 100% were considered excessive and an indication of inaccuracy in velocity measures. Back calculation of spawning sites utilized drift rates of 100% and 71% in association with the Red and Washita Rivers, respectively.

SPAWNING SITE ESTIMATION

Viable eggs made up 61% to 87% of Red River eggs collected from 2002 to 2004. My estimates of spawning locations suggested that striped bass spawning in 2002, 2003, and 2004 primarily occurred from 80 to 119 km and from 130 to 149 km up river of Lake Texoma (Figures 13-15). In 2002, 18% of viable eggs collected were determined to originate in that area 80 to 119 km up river. Thirty-eight percent of viable eggs collected were determined to originate 130 to 149 km up river. An additional 19% of viable eggs collected originated in the area 60 to 80 km up river. In 2003, 81% of viable eggs collected were determined to originate in the area 90 to 99 km up river. Eighteen percent of viable eggs collected were determined to originate 140 to 149 km up river. In 2004, 35% of viable eggs collected were back calculated to an area 80 to 99 km up river. Thirty-eight percent of viable eggs collected were determined to originate 130 to 139 km up river.

Viable eggs made up 67% to 78% of Washita River eggs collected from 2002 to 2004. My estimates of spawning locations suggested Washita River striped bass spawning in 2002, 2003, and 2004 primarily occurred between 50 and 109 km of Lake Texoma (Figures 16-18). In 2002, 89% of viable eggs collected were determined to originate in the area 70 to 99 km up river. Approximately, half (47%) of viable eggs collected were determined to originate between 70 and 79 km. Twenty-one percent of viable eggs collected were determined to originate 90 to 109 km up river. In 2003, 84% of viable eggs collected were determined to originate in the area 50 to 89 km up river. Thirty-five percent of those were specifically from 70 to 79 km up river. In addition,

14% of viable eggs collected were determined to originate 90 to 109 km up river. In 2004, 85% of viable eggs collected were back calculated to an area 50 to 79 km up river. Approximately half (43%) of those were determined to originate 70 to 79 km up river. Five percent of viable eggs originated 90 to 99 km up river.

DISCUSSION

Despite expectations of striped bass egg sampling efficiency differing by river, little between-river differences were found in sampling efficiency. Overlapping confidence intervals of efficiency estimates supported the insignificance of these differences. The minimal difference in efficiency estimates was evident in comparison of egg collections prior to and following efficiency corrections. Although efficiency measures differed little between rivers, the factors controlling efficiency did appear to be unique within each river system.

Reinert et al. (2004) suggested that sampling efficiency in the Savannah River system was influenced by channel width and depth. Multiple regression analysis indicated that a similar relationship occurs in the Red and Washita Rivers. Discharge in the Red River readily influenced channel width and although discharge played a role in determining efficiency in both river systems, it appeared to be most influential in the Red River. Under the same criteria, the Washita River, which changes little in channel width under variable discharge, would be less influenced by discharge as results indicated. In both rivers, discharge alone explained only a portion of the variability in efficiency measures. Sampled volume (m^3), in both river systems had little or no influence on efficiency measures, but sample site depth and the combination of depth and discharge

did significantly influence efficiency. The combination of discharge and sample site depth was most influential in the Washita River.

Differences in Red and Washita River channel morphology were most likely responsible for effective differences in sample site depth as they relate to sampling efficiency. The wide unconfined channel of the Red River allowed water to expand, influencing depth in small increments (personal observations of the investigator). The confined channel of the Washita River did not allow water to expand significantly, influencing depth in larger increments (personal observations of the investigator). Rulifson et al. (1993) demonstrated that striped bass eggs evenly disperse vertically in the water column. Although, this principle was not tested with gelatin beads, it seems reasonable that gelatin beads and striped bass eggs were similar enough in physical characteristics to support this assumption to some degree (Chapter I). Therefore, as depth increased a smaller proportion of the total number of gelatin beads present might have been within the sampled zone.

Despite reasonable explanation of differences between river efficiencies, much of the variability in the data remained unexplained. Certainly, the imprecision of working in natural river systems was responsible for a good portion of this variability. Standardization of sampling efficiency estimation procedures should have maintained the applicability of comparisons between rivers.

Insignificant differences in tested efficiency net pairs indicated that gelatin beads released in sampling efficiency trials were evenly distributed in sampled areas of the channel in both the Red and Washita Rivers and that net placement based on observed areas of primary current did not create differences in efficiency measures between net

pairs. Results from efficiency estimate net pair comparisons for Red River samples were potentially affected by the location of the nets fished from the boat at sites R2 and R3. The boat rigging allowed two nets to be fished simultaneously, but limited net separation to approximately 5 m. Nets fished from bridges were set in the most visible areas of river current and typically were set considerably further than 5 m apart. Boat collected samples might have acted more as paired samples thus reducing the variability between samples by location rather than gelatin bead distribution.

Measured efficiencies determined under the described protocol were useful in adjusting striped bass egg collections for comparability. Given the desired objective of determining the importance of each involved river systems in relation to striped bass recruitment of Lake Texoma, these adjustments functioned well. However, the estimates were not generally applicable for estimation of total egg production. Accurate estimation of egg production based on efficiency measurements requires different methodology. Measurement of efficiency through gelatin bead releases at predetermined spawning locations would have provided increased accuracy for total egg production estimates. Releases could also be coordinated with spawning activity for use in mark recapture estimates.

Mark recapture estimates were attempted during preliminary efforts on this project, but were discontinued due to logistical difficulties. Difficulties encountered included accessing spawning locations, timing releases with egg deposition, and timing recaptures. In addition, it was demonstrated that gelatin beads had the potential to overestimate sampling efficiency due to differences in diameter and density (Chapter I). It might have been possible to improve the accuracy of gelatin beads as striped bass egg

surrogates by manipulating specific gravity. As evident in Chapter I specific gravity of gelatin beads can be manipulated by the salinity of the solution in which they are washed.

Striped bass egg production, as evident through egg collections from 2002 to 2004, followed a pattern similar to that described by Baker (2003) in 2001. Spawning coincided with increases in water temperature to 14 - 18°C and culminated shortly after temperatures reach excessive levels at approximately 25°C. Peak egg production generally occurred following peak discharge events.

Striped bass egg production analyses by all daily summed egg collections and daily summed egg collections during peak production periods only did not conflict, but were complimentary. However, the inferential statistics associated with peak production periods demonstrated a greater ability to detect differences generally observed in the data. Therefore, discussion relative to between river comparisons was primarily based on analysis of peak production period data.

Adjusted striped bass egg numbers in the Washita River were greater in all years. However, Red River striped bass egg collections were significantly less than those of the Washita River only in 2001 and 2003. Red River viable striped bass egg collections compared between years indicated that collections in 2003 differed from all years except 2002. Striped bass egg collections in 2002 were not conducted on several occasions due to high water levels. Resulting similarities between 2003 and 2002 might be an indication of the reduced number of samples rather than similarities in egg production. However, limitations were most likely minor, as 2002 did not differ from either 2001 or 2004. Washita River striped bass egg estimates between years differed only in 2002. Washita River striped bass egg collections in 2002 were also interrupted by high water.

Differences in egg collections most likely reflected this reduction in effort given that Washita River striped bass egg collections in 2002 differed from all other years.

Rulifson and Manooch (1990) and Zincone and Rulifson (1991) suggested that moderate in-stream flow volume, including spikes in the hydrograph associated with typical spring weather, were influential in striped bass recruitment in the Lower Roanoke River, North Carolina. River flows in the Red River during April and May of 2003 were well below the 64-year average. Washita River discharge was also consistently low in 2003. Only one peak flow period occurred in both rivers during the egg production period. Egg production peaked on both rivers in association with these peak flows. Low water conditions were also experienced in 2004, although to a lesser extent than 2003.

Despite the extreme low water conditions of 2003 and relatively similar conditions of 2004, corrected egg estimates combined by river and compared between years did not significantly differ in any year from 2001 to 2004. Analysis suggested that low water conditions might negatively influence egg production as in the Red River 2003, but that low water alone does not limit population-wide recruitment. Consistent egg production in the Washita River despite low flow conditions in 2003 provided evidence of the stabilizing strength of the Washita River. Therefore, I would have expected the relative importance of the Washita River to be greater than the Red River in reference to its contributions in striped bass egg productions.

Estimates of striped bass drift rate as a percentage of water velocity have been reported previously in the literature. Davin et al. (1999), used gelatin beads, just as those used in this research, to estimate striped bass egg drift in the Savannah River system, Georgia. Results from Davin et al. (1999) indicated gelatin beads traveled at an average

65% of water velocity. Resulting estimated drift in the Washita River was comparable to that of the Savannah River research. However, estimated drift from the Red River varied considerably from both the Savannah and Washita River estimates. Observed differences may be have been due to the nature of currents in each river. The Red River was considerably less sinuous than the Washita River. Lower sinuosity might have resulted in the potential for less diverse current. Current diversity, including eddies and backwater locations might have slowed the rate of gelatin bead travel by providing areas to settle out of the main current. The Savannah River system had a series of tidally influenced braided channels that potentially created considerably diverse currents (Davin et al. 1999). Similarly, the Washita River, although maintaining a defined channel, was considerably more sinuous, potentially creating a greater opportunity for diverse current features that may slow mean drift rate.

The accuracy of velocity estimates also might have played a role in the determination of drift rates. Velocity models were based on historical data collected at a single location on the Washita River and two locations on the Red River. USGS gauging stations on the Red River were located on either end of the sampled stretch. The upper-most USGS gauging station, located at Terral, Oklahoma was approximately 63 km upstream from sample site R1. Although, this location should have more accurately described the upper river values than the lower most gauging station, inconsistencies with actual velocity may still occur as this area is outside the actual sampled reach. However, when analyzed separately, estimated drift rate from the lower most sample site R3, located at Interstate 35 remained high at 111%. The sample site at Interstate 35 was also the location of the second gauging station and within the sampled reach. Washita River

velocities were taken from a single centrally located USGS gauging station. Some error is expected from estimates based on historical data due to changes in the river channel at set gauging stations over time.

Gelatin bead sampling protocol also potentially affected drift rate estimates. Gelatin beads collected in areas of primary current were likely to travel at rates closer to maximum water velocity. As drift rates were determined by mean water velocity, values of over 100% are possible. Red River drift rate estimates were most likely to be influenced by sampling protocol issues. Gelatin bead collections at sample sites R2 and R3 were taken using nets rigged on the boat apparatus. Minimal net spread due to use of the boat apparatus meant that both nets were centrally located in the highest velocity water. Typically, nets hung from bridges occupied the primary area of current and a secondary area of current, also considered high velocity areas.

Estimated primary-spawning locations identified in the Red and Washita Rivers were relatively consistent with those identified by Baker (2003) in 2001. Red River spawning sites identified in 2001 were located between 60 and 69 km, 90 and 109 km, and 140 and 159 km up river of Lake Texoma. Spawning from 2002 to 2004 in the area of the Red River 60 to 69 km up river was determined to be a location of significant spawning in 2002 only. Washita River spawning sites identified in 2001 were located 70 to 89 km and 100 to 109 km up river. Striped bass spawning in the Washita River from 2002 to 2004 occurred primarily within the lower most area identified in 2001, 70 to 79 km up river. Baker (2003) demonstrated that eggs associated with these spawning locations hatched throughout the Red River and within 40 km of Lake Texoma in the Washita River.

Although spawning locations identified in the Red and Washita Rivers from 2002 to 2004 incorporated those areas described in 2001, resulting back calculations exhibited high variability. Much of the variability in estimating spawning locations can be associated with the measures used in estimation. Measures included estimates of travel rate, water velocity, and egg development. In addition, drift rates used to describe spawning areas in 2001 were based on 65% of water velocity as reported by Davin et al. (1999) (Baker 2003). Spawning locations estimated in 2002 through 2004 based on drift rates of 100 and 71% in the Red and Washita Rivers, respectively might have incorporated areas further up river than estimates based on 65% drift rate. The patterns observed in spawning site distribution did not show extreme deviation when adjustments of drift rates were made. Under drift rates of 65%, primary spawning locations were approximately 10 km below locations based on 100% and 71% drift.

Despite the relative inaccuracy of the measures used to identify spawning locations, some confidence was provided from in river observations identified by Baker (2003). Estimated spawning locations were within areas in each river where rocky substrate was observed or reported(Baker 2003). Striped bass spawning habitat were considered as areas of turbulent water typically associated with rocky substrate (Albrecht 1964; Combs 1980; Kornegay and Humphries 1976). Rocky substrate, often associated with turbulent water, was not typical of the majority of either river system. Therefore, spawning site fidelity in the Red and Washita Rivers might be associated more with habitat limitations than behavioral adaptation. If this is true, the preservation of these sites suitable for spawning and continued access by striped bass to such sites is of particular importance if continued natural reproduction of striped bass in the system is

desired. Despite low flows during 2003 and 2004 Red River egg production was estimated to occur a considerable distance upstream from Lake Texoma. Results suggested that low water levels in the Red River did not limit access to spawning areas.

Reported spawning locations in the Washita River include the location 100-109 km up river referred to as the Dolese gravel crusher. The Dolese gravel crusher was identified as the primary spawning location in investigations by Baker (2003) and previously by Oklahoma Department of Wildlife personnel (Paul Mauck, personal communication). Although my data indicated this site was associated with spawning in all years, collected samples did not indicate it was utilized as heavily as in 2001. However, Baker (2003) found that the majority of spawning at this location occurred on one day. Due to the alternating nature of the sampling schedule and sampling days missed, samples may not have been coordinated with such an occurrence. During the spring of 2002, egg collections were discontinued during the primary peak in the hydrograph. Peak egg production typically followed peaks discharge. Therefore, collections made in 2002 may not have reflected all spawning occurrences. Discharge levels during the striped bass egg collection period of 2003 and 2004 were considerably lower than the previous two years. Due to low water, that area associated with the gravel crusher may be less accessible or less desirable to spawning striped bass. Although spawning probably did occur at the gravel crusher, the majority of striped bass eggs back calculated to this area from 2002 to 2004 were determined to originate just down stream of the gravel crusher (90 to 99 km). Smaller scale areas of rocky substrate can be found for several kilometers downstream of the gravel crusher location.

If striped bass eggs hatched throughout the Red River as estimated by Baker (2003), egg collections alone might not be the best measure for comparison of striped bass recruitment in this system. Although, ideally striped bass egg sampling protocol was able to detect the primary patterns in striped bass egg deposition in each river, the staggered sample schedule and location of sample sites might not be completely effective in the Red River if hatching occurs upstream to sampling locations. Larval fish collected in netting efforts were not routinely identified or enumerated. Therefore, the opportunity to capture and identify Red River striped bass eggs was limited by the location of egg hatching. Striped bass egg hatching in the Washita River primarily occurred below the lowest sample site providing a greater opportunity for an individual egg to be captured.

Defining striped bass egg and larval survival is perhaps the next step in understanding the recruitment contributions of the Red and Washita Rivers. If recruitment is in some way limited in the Texoma system by egg or larval survival, the influences of egg production may be less important. Bulak et al. (1997) suggested that larval survival depends on transport of eggs and larval striped bass to high-quality nursery habitat. Research is currently being conducted to determine the relative quality of lower river reaches and upper lake areas in the Lake Texoma system as nursery habitat for larval striped bass (Jason Schaffler, Graduate Assistant, Oklahoma State University, personal communication). Provided that nursery habitat is sufficient in both systems, defining the proportion of eggs that survive to larval stages at suitable nursery habitat is important for understanding the larger picture of recruitment.

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Table 1. Red River efficiency measures from net pairs (A and B = nets) indicated by discharge category, sample site, and discharge at which they were measured.

Discharge Range (m^3s^{-1})	Site	Discharge (m^3s^{-1})	Efficiency (%) A	B
LOW (10-190)	R1	15	0.144	0.210
		19	0.286	0.226
		25	0.164	0.038
		94	0.002	0.001
		110	0.011	0.028
	R2	18	0.170	0.202
		22	0.159	0.137
		27	0.336	0.246
		49	0.106	0.092
		161	0.076	0.057
	R3	19	0.010	0.143
		23	0.173	0.152
		31	0.188	0.178
		55	0.178	0.122
		148	0.013	0.002
MEDIUM (190-370)	R2	191	0.048	0.063
		235	0.066	0.042
	R3	299	0.001	0.014
		320	0.136	0.003
HIGH (370-550)	R2	469	0.080	0.122
	R3	569	0.056	0.058

Table 2. Washita River efficiency measures from net pairs (A and B = nets) indicated by discharge category, sample site, and discharge at which they were measured.

Discharge Range (m^3s^{-1})	Site	Discharge (m^3s^{-1})	Efficiency (%) A	B
LOW (5-51)	W1	22	0.161	0.081
		27	0.172	0.182
		46	0.147	0.183
	W2	15	0.152	0.115
		27	0.192	0.032
		48	0.111	0.082
	W3	15	0.136	0.114
		27	0.264	0.137
		50	0.135	0.114
MEDIUM (52-97)	W1	65	0.280	0.287
		68	0.107	0.113
		94	0.100	0.075
	W2	88	0.061	0.103
	W3	62	0.047	0.067
HIGH (98-143)	W2	108	0.067	0.102
	W3	125	0.035	0.054

Table 3. Paired t-test ($P \leq 0.05$) used to detect differences in efficiency estimates (%) between A-B net pairs.

RIVER	Net	N	t	p	df
RED	A	21	0.95	0.3518	20
	B	21			
WASHITA	A	16	1.4	0.1804	15
	B	16			

Table 4. Results of multiple regression analysis by modeled variables, used to define the factors affecting efficiency measures in the Red River. Results include analysis of variance and r^2 values.

	df	ss	ms	F	p	r^2
Discharge (m^3s^{-1})						
Model	1	0.0439	0.0439	8.66	0.0068	0.25
Error	26	0.1317	0.0051			
Corrected total	27	0.1756				
Sampled Volume (m^3)						
Model	1	0.0002	0.0002	0.03	0.8548	0.00
Error	26	0.1753	0.0067			
Corrected total	27	0.1756				
Depth (m)						
Model	1	0.0041	0.0041	0.63	0.4362	0.02
Error	26	0.1714	0.0066			
Corrected total	27	0.1756				
Discharge+Volume						
Model	2	0.0444	0.0222	4.24	0.0260	0.25
Error	25	0.1311	0.0052			
Corrected total	27	0.1756				
Discharge+Depth						
Model	2	0.0663	0.0332	7.59	0.0027	0.38
Error	25	0.1092	0.0044			
Corrected total	27	0.1756				
Volume+Depth						
Model	2	0.0042	0.0021	0.31	0.7377	0.02
Error	25	0.1713	0.0069			
Corrected total	27	0.1756				
Discharge+Volume+Depth						
Model	3	0.0687	0.0229	5.15	0.0069	0.39
Error	24	0.1068	0.0045			
Corrected total	27	0.1756				

Table 5. Results of multiple regression analysis by modeled variables, used to define the factors affecting efficiency measures in the Washita River. Results include analysis of variance and r^2 values.

	df	ss	ms	F	p	r^2
Discharge (m^3s^{-1})						
Model	1	0.0123	0.0123	2.67	0.1229	0.15
Error	15	0.0690	0.0046			
Corrected total	16	0.0813				
Sampled Volume (m^3)						
Model	1	0.0000	0.0000	0.01	0.9369	0.00
Error	15	0.0812	0.0054			
Corrected total	16	0.0813				
Depth (m)						
Model	1	0.0350	0.0350	11.32	0.0043	0.43
Error	15	0.0463	0.0031			
Corrected total	16	0.0813				
Discharge+Volume						
Model	2	0.0160	0.0080	1.72	0.2153	0.20
Error	14	0.0654	0.0047			
Corrected total	16	0.0813				
Discharge+Depth						
Model	2	0.0538	0.0269	13.69	0.0005	0.66
Error	14	0.0275	0.0020			
Corrected total	16	0.0813				
Volume+Depth						
Model	2	0.0398	0.0199	6.71	0.0090	0.50
Error	14	0.0415	0.0030			
Corrected total	16	0.0813				
Discharge+Volume+Depth						
Model	3	0.0539	0.0180	8.55	0.0022	0.66
Error	13	0.0273	0.0021			
Corrected total	16	0.0813				

Table 6. Depth range for standard sample sites including range of associated discharge values. Measurements were made on a limited basis (Red River N=11, Washita River N=10) during efficiency trials.

Site	m^3s^{-1}	Depth (m)
R1	19-110	0.50-1.25
R2	22-235	1.50-3.0
R3	19-320	2.25-3.25
W1	22-68	1.0-2.0
W2	15-88	1.0-2.0
W3	15-125	0.75-3.75

Table 7. Egg catch per unit effort (CPUE; number/10-min sample) between rivers within years not corrected for efficiency. Significant differences in nonparametric statistics were assumed to represent differences in mean values. N=number of days, CV=Coefficient of Variation. Mean ranks with different superscripts were statistically different (Wilcoxon rank sum test; $P \leq 0.05$).

RIVER	N	MIN	MAX	MEDIAN	MEAN	MEAN RANK	CV
				2001			
RED	19	0	865	18	114	17.1^{a}	187.82
WASHITA	19	0	7216	50	691	21.9^{a}	252.75
				2002			
RED	14	0	375	42	72	10.4^{a}	143.61
WASHITA	11	0	2381	156	355	15.5^{a}	196.85
				2003			
RED	15	0	379	0	37	11.7^{a}	266.13
WASHITA	14	0	9462	14.5	951	18.5^{b}	267.39
				2004			
RED	19	0	3491	41	447	18.5^{a}	189.55
WASHITA	19	0	5031	123	796	20.5^{a}	175.40

Table 8. Egg catch per unit effort (CPUE; number/10-min sample) between rivers within years corrected by efficiency measures. Significant differences in nonparametric statistics were assumed to represent differences in mean values. N=number of days, CV=Coefficient of Variation. Mean ranks with different superscripts were statistically different (Wilcoxon rank sum test; $P \leq 0.05$).

RIVER	N	MIN	MAX	MEDIAN	MEAN	MEAN RANK	CV
			2001				
RED	19	0	6.77E+06	125938	585101	17.6[a]	263.14
WASHITA	19	0	2.14E+07	147216	2.04E+06	21.4[a]	253.16
			2002				
RED	14	0	2.94E+06	77227	474248	11.6[a]	178.86
WASHITA	11	0	5.24E+06	651533	1.08E+06	14.8[a]	142.91
			2003				
RED	15	0	700504	0	67439	11.6[a]	266.45
WASHITA	14	0	2.08E+07	31918	2.09E+06	18.6[b]	267.39
			2004				
RED	19	0	7.41E+06	75819	1.15E+06	18.8[a]	188.92
WASHITA	19	0	1.11E+07	270286	1.75E+06	20.2[a]	175.40

Table 9. Egg catch per unit effort (CPUE; number passing/10-min sample) measures by river between years corrected by efficiency. Significant differences in nonparametric statistics were assumed to represent differences in mean values. N=number of days, CV=Coefficient of Variation. Mean ranks were significantly different (Kruskal-Wallis nonparametric one-way ANOVA; $P \leq 0.05$). However, all pairwise comparisons indicated difference only at $P \leq 0.10$, signified by mean ranks with different superscripts.

YEAR	N	MIN	MAX	MEDIAN	MEAN	MEAN RANK	CV
			RED RIVER				
2001	19	0	1.97E+06	36527	173048	38.7^{a}	258.04
2002	14	0	852098	25084	138551	34.9^{ab}	177.23
2003	15	0	227530	0	21905	21.5^{b}	266.45
2004	19	0	2.15E+06	24627	357820	38.5^{a}	185.48
			WASHITA RIVER				
2001	19	0	5.82E+06	40118	556375	33.2^{a}	252.84
2002	11	0	1.71E+06	177552	297865	34.4^{a}	166.55
2003	14	0	6.79E+06	10401	682108	29.0^{a}	267.39
2004	19	0	3.61E+06	88077	570731	31.7^{a}	175.4

Table 10. Egg catch per unit effort (CPUE; number passing/10-min sample) measures by year for combined rivers corrected by efficiency. Significant differences in nonparametric statistics were assumed to represent differences in mean values. N=number of days, CV=Coefficient of Variation. Mean ranks with different superscripts were statistically different (Kruskal-Wallis nonparametric one-way ANOVA; $P \leq 0.05$).

YEAR	N	MIN	MAX	MEDIAN	MEAN	MEAN RANK	CV
			Rivers Combined				
2001	38	0	5.82E+06	38323	364712	71.3[a]	287.24
2002	25	0	1.71E+06	38709	208649	67.8[a]	180.42
2003	29	0	6.79E+06	4304	340624	50.2[a]	378.13
2004	38	0	3.61E+06	60040	464276	69.9[a]	181.93

Table 11. Peak production period egg catch per unit effort (CPUE; number/10-min sample) between rivers within years corrected by efficiency measures. N=number of days, CV=Coefficient of Variation. Means with different superscripts were statistically different (two sample t-test; $P \leq 0.05$).

RIVER	N	MIN	MAX	MEDIAN	MEAN	CV
			2001			
RED	4	276773	1.97E+06	305236	713131[a]	117.10
WASHITA	3	1.78 E+06	5.82E+06	2.09 E+06	3.23 E+06[b]	69.63
			2002			
RED	4	212518	852098	372181	452244[a]	61.29
WASHITA	6	177552	1.71E+06	247252	528429[a]	112.14
			2003			
RED	3	32217	227530	40141	99963[a]	110.59
WASHITA	2	1.85 E+06	6.79E+06	4.32 E+06	4.32 E+06[b]	80.98
			2004			
RED	6	337921	2.15E+06	708627	1.06 E+06[a]	79.24
WASHITA	5	1.08 E+06	3.61E+06	1.85 E+06	1.99 E+06[a]	51.97

Table 12. Peak production period egg catch per unit effort (CPUE; number passing/10-min sample) measures by river between years corrected by efficiency. N=number of days, CV=Coefficient of Variation. Means with different superscripts were statistically different (one-way ANOVA; $P \leq 0.05$).

YEAR	N	MIN	MAX	MEDIAN	MEAN	CV
			RED RIVER			
2001	4	276773	1.97E+06	305236	713131[a]	117.10
2002	4	212518	852098	372181	452244[ab]	61.29
2003	3	32217	227530	40141	110548[b]	110.59
2004	6	337921	2.15E+06	708627	841609[a]	79.24
			WASHITA RIVER			
2001	3	1.78E+06	5.82E+06	2.09 E+06	3.23 E+06[a]	69.63
2002	6	177552	1.71E+06	247252	528429[b]	112.14
2003	2	1.85E+06	6.79E+06	4.32 E+06	4.32 E+06[a]	80.98
2004	5	1.08E+06	3.61E+06	1.85 E+06	1.99 E+06[a]	51.972

Table 13. Peak production period egg catch per unit effort (CPUE; number passing/10-min sample) measures by year for combined rivers corrected by efficiency. Significant differences in nonparametric statistics were assumed to represent differences in mean values. N=number of days, CV=Coefficient of Variation. Mean ranks with different superscripts were statistically different (Kruskal-Wallis nonparametric one-way ANOVA; $P \leq 0.05$).

YEAR	N	MIN	MAX	MEDIAN	MEAN	MEAN RANK	CV
			Rivers Combined				
2001	7	276773	5.82E+06	1.78 E+06	1.79 E+06	19.7[a]	109.42
2002	10	177552	1.71E+06	305006	497955	11.3[a]	94.97
2003	5	32217	6.79E+06	227530	1.79 E+06	13.0[a]	162.17
2004	11	337921	3.61E+06	1.14 E+06	1.48 E+06	22.3[a]	67.95

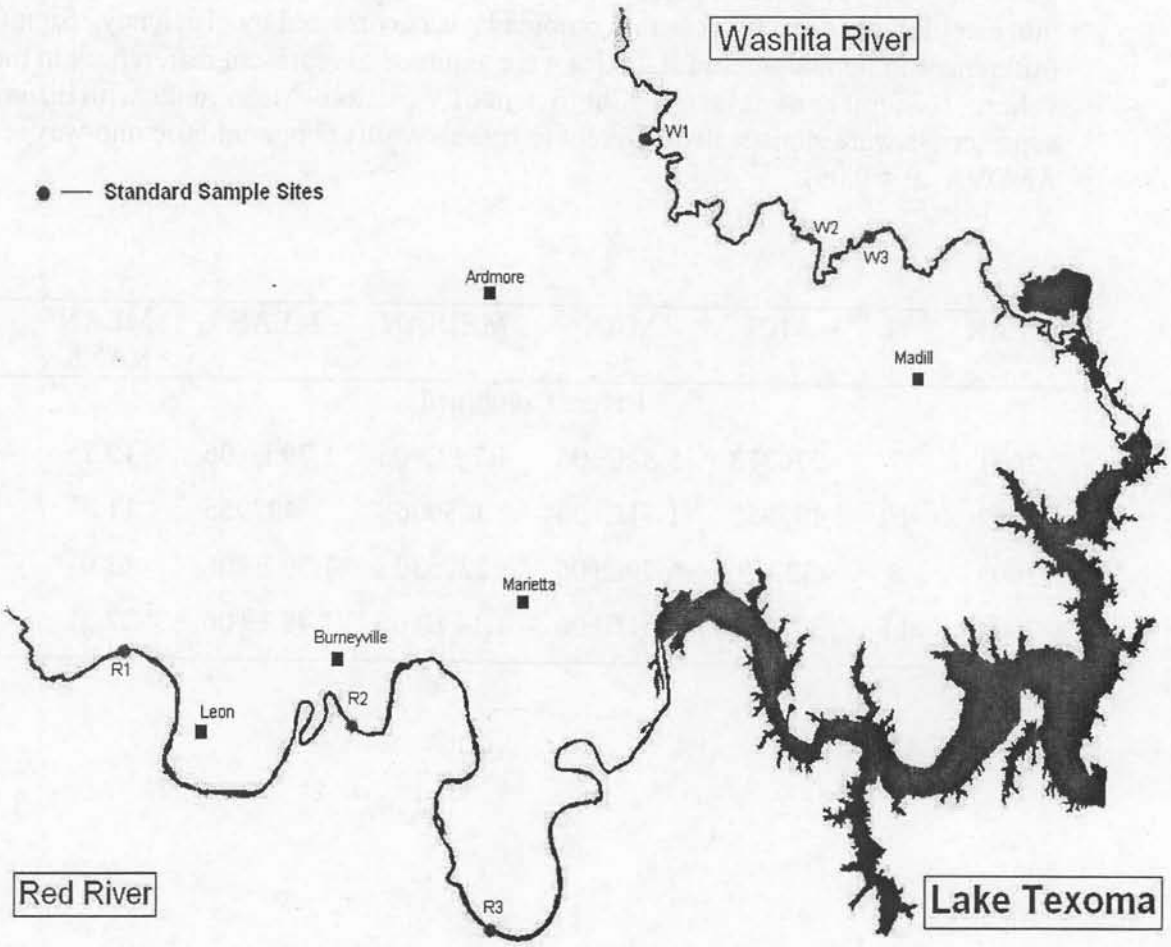

Figure 1. Map of standard sample sites on the Red and Washita Rivers, Oklahoma

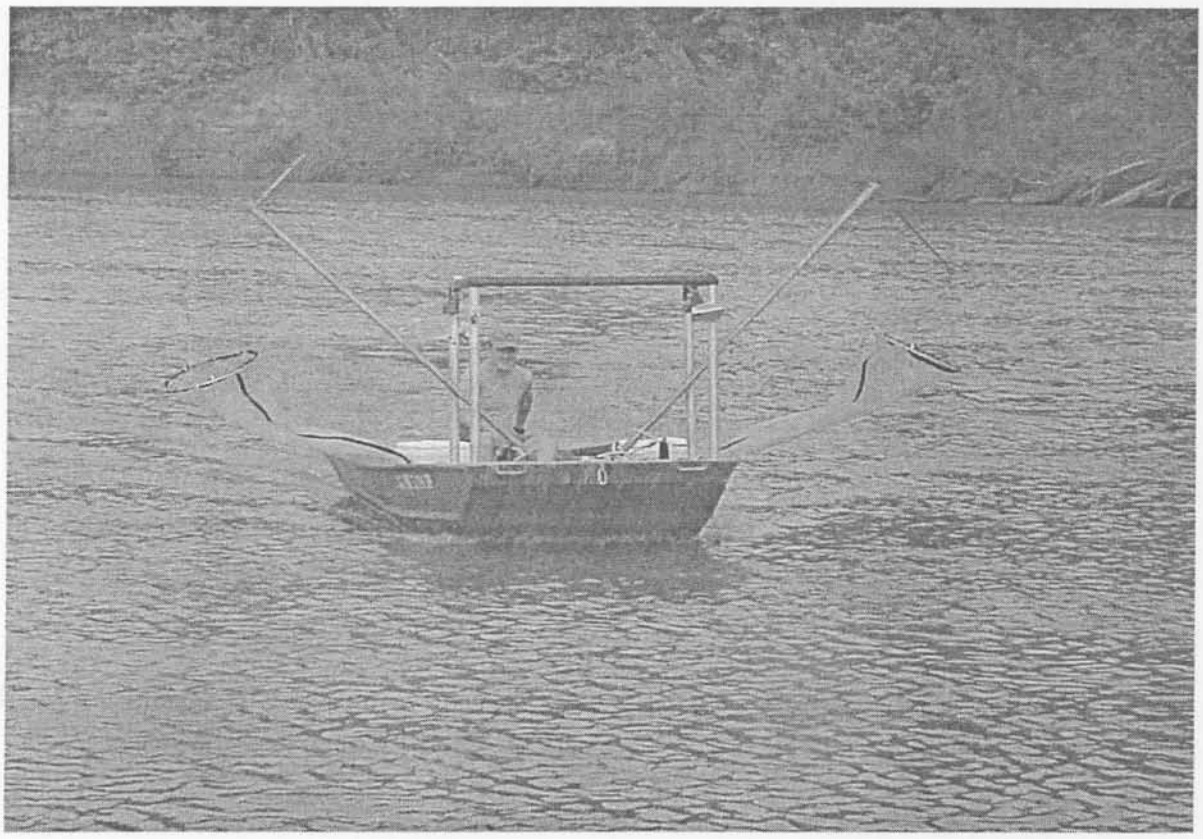

Figure 2. Net rigging used in boat collected samples at R2 and R3, Red River.

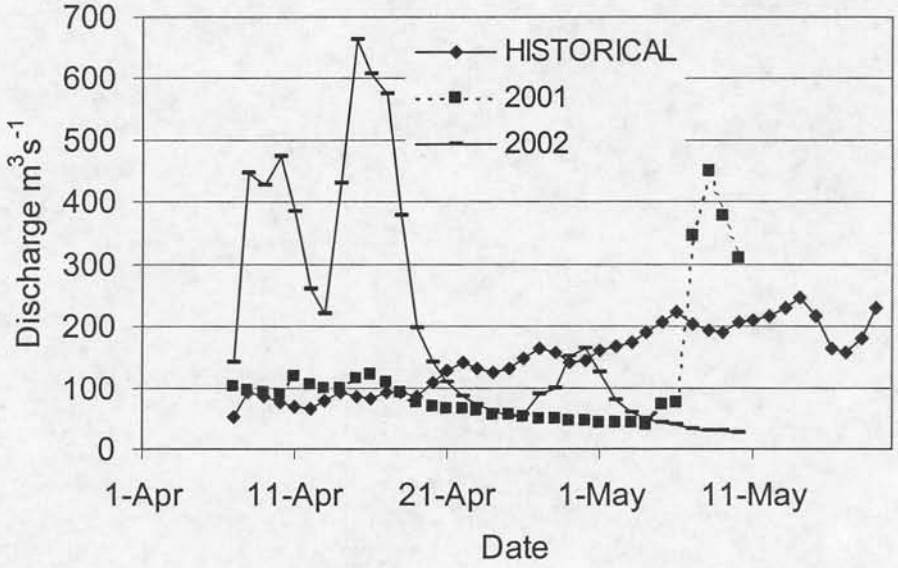

Figure 3. Mean daily discharge for Red River near Gainesville, Texas, during April and May 2001, 2002, and historical mean daily discharge based on 64 years of record.

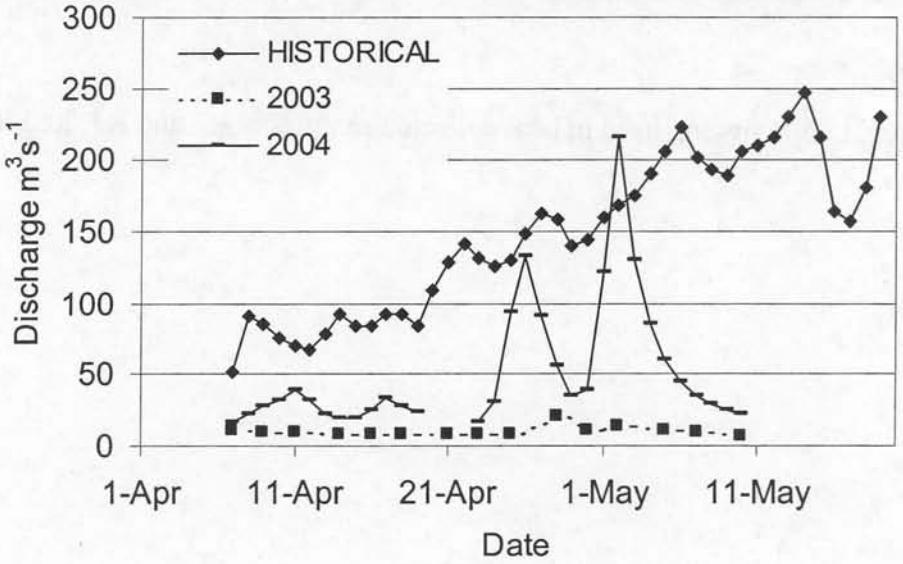

Figure 4. Mean daily discharge for Red River near Gainesville, Texas, during April and May 2002, 2003, and historical mean daily discharge based on 64 years of record. Note difference in scale from figures 3, 5, and 6.

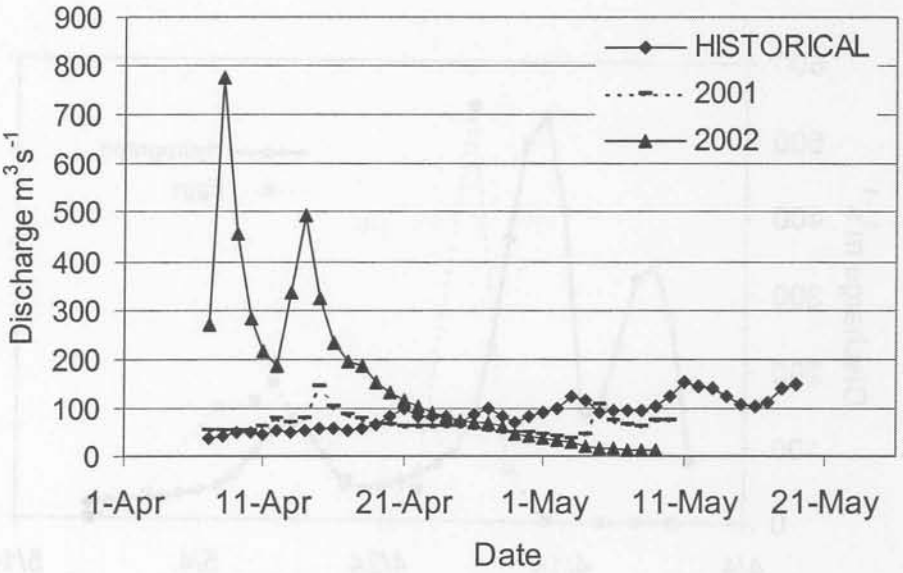

Figure 5. Mean daily discharge for Washita River near Dickson, Oklahoma during April and May 2001, 2002, and historical mean daily discharge based on 64 years of record. Note difference in scale from figures 3, 4, and 6.

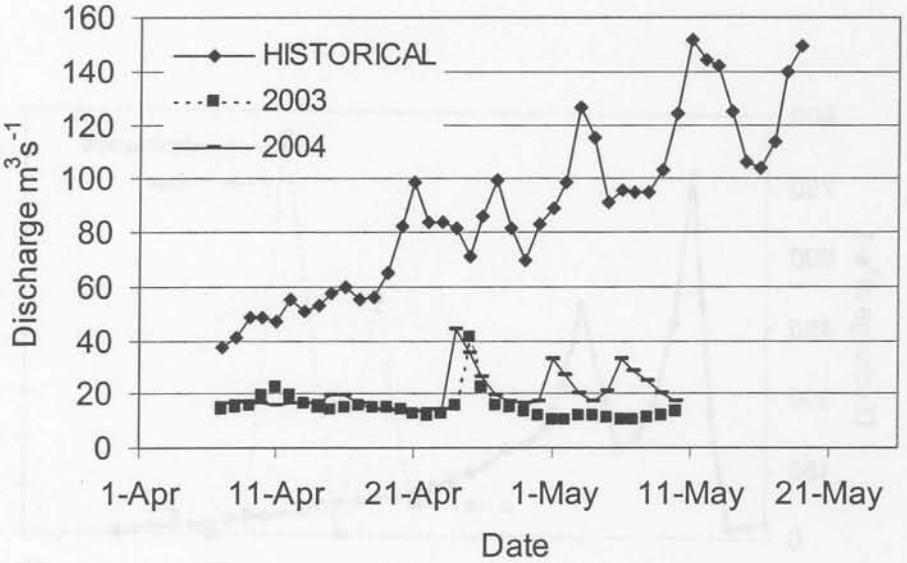

Figure 6. Mean daily discharge for Washita River near Dickson, Oklahoma during April and May 2003, 2004, and historical mean daily discharge based on 64 years of record. Note difference in scale from figures 3, 4, and 5.

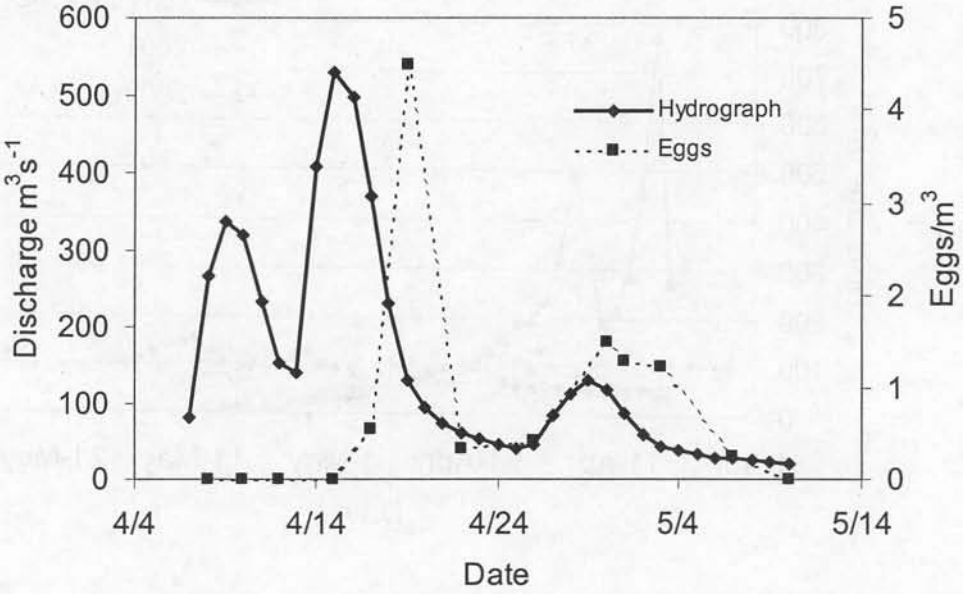

Figure 7. Mean daily egg catch (eggs/m^3) collected in the Red River 2002 in relation to mean daily discharge (m^3s^{-1}).

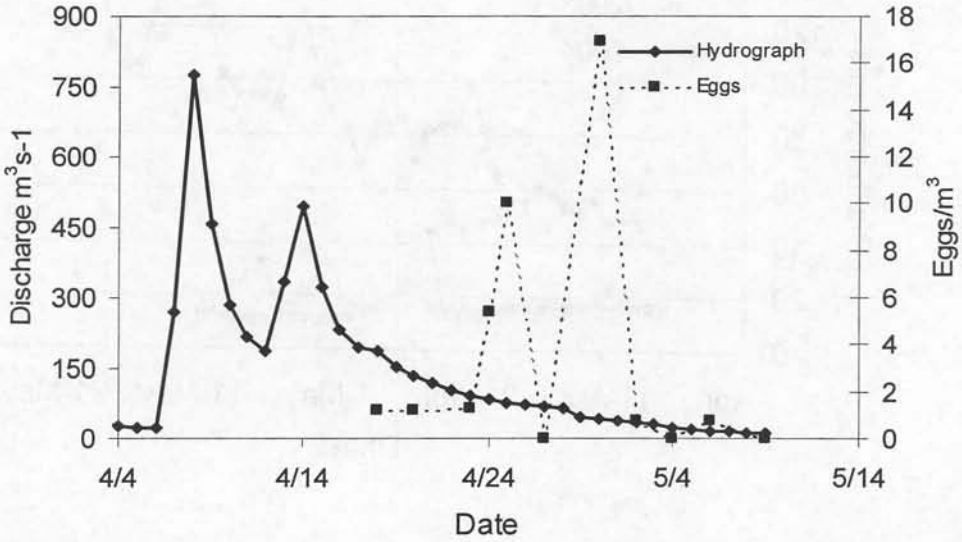

Figure 8. Mean daily egg catch (eggs/m^3) collected in the Washita River 2002 in relation to mean daily discharge (m^3s^{-1}).

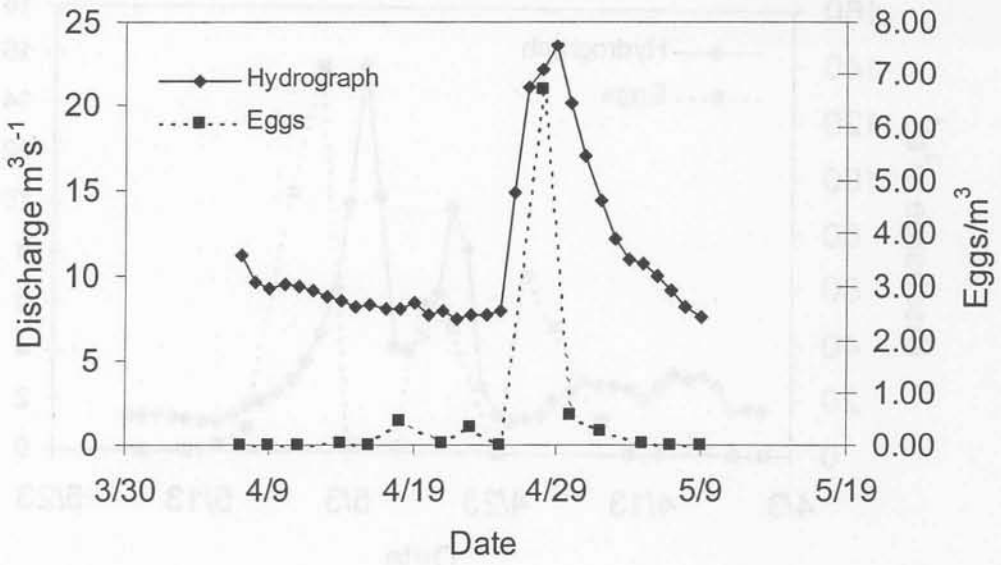

Figure 9. Mean daily egg catch (eggs/m^3) collected in the Red River 2003 in relation to mean daily discharge (m^{3}s^{-1}).

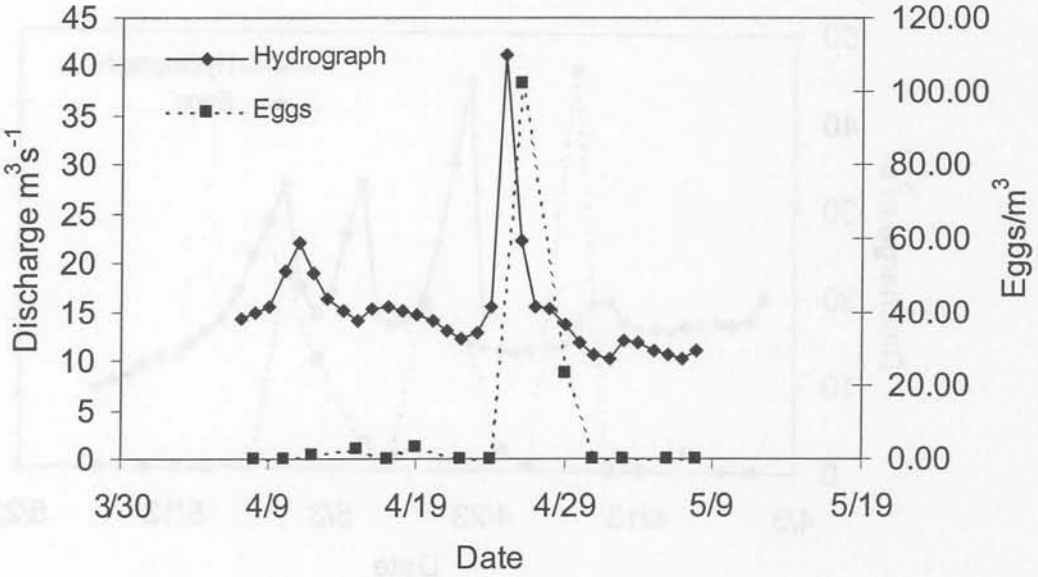

Figure 10. Mean daily egg catch (eggs/m^3) collected in the Washita River 2003 in relation to mean daily discharge (m^{3}s^{-1}).

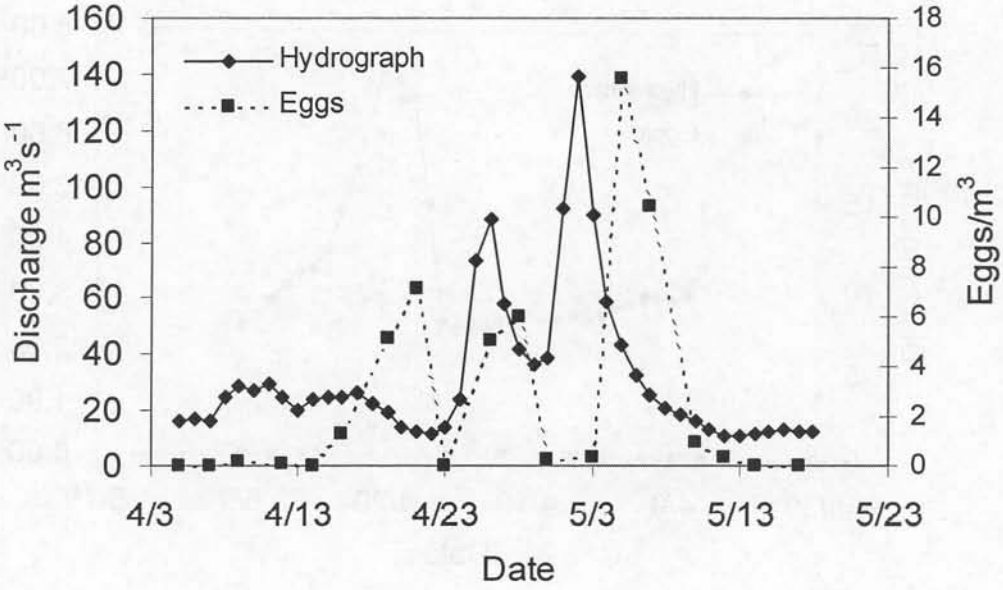

Figure 11. Mean daily egg catch (eggs/m^3) collected in the Red River 2004 in relation to mean daily discharge (m^{3}s^{-1}).

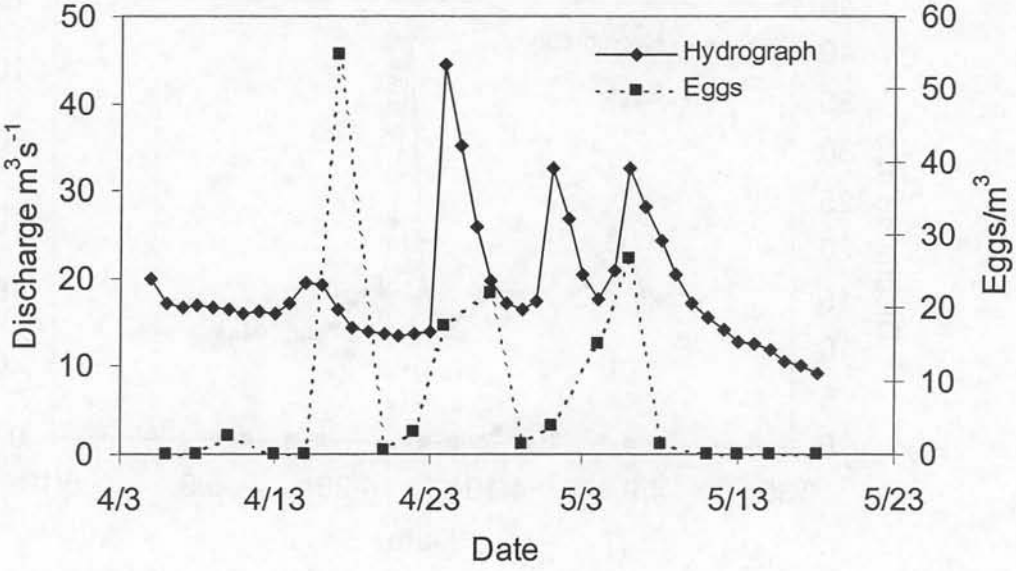

Figure 12. Mean daily egg catch (eggs/m^3) collected in the Washita River 2004 in relation to mean daily discharge (m^{3}s^{-1}).

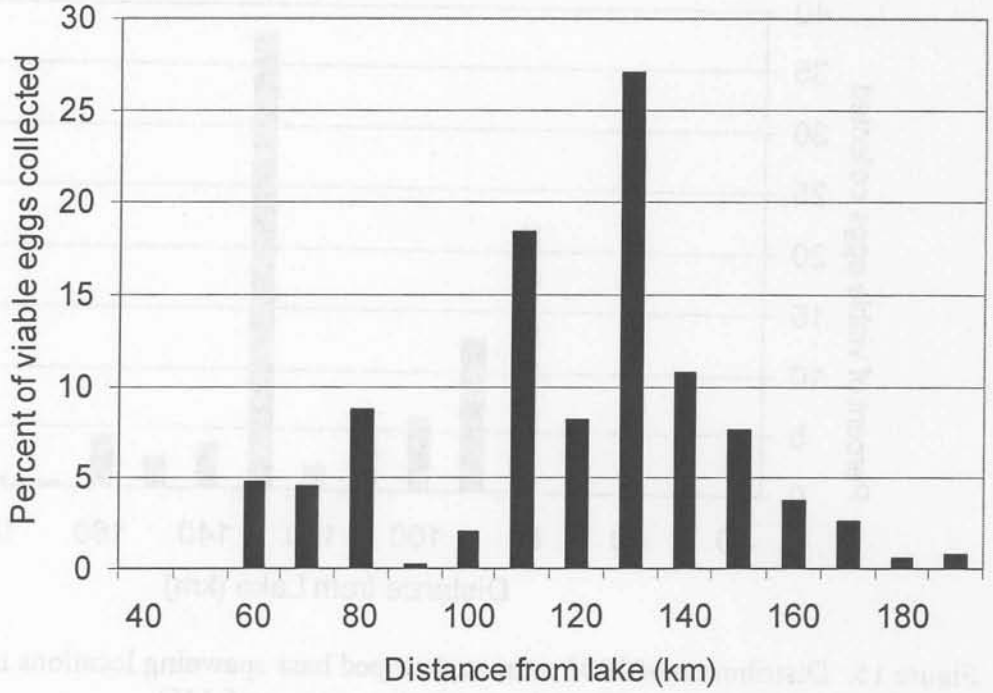

Figure 13. Distribution of 2002 estimated striped bass spawning locations in the Red River based on staged eggs from three sampling sites (n=528).

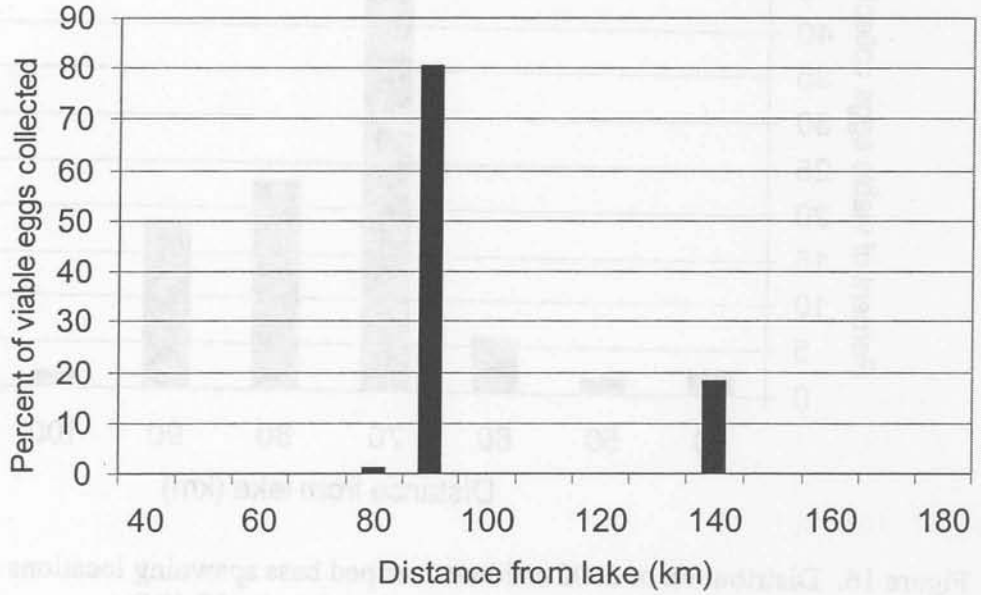

Figure 14. Distribution of 2003 estimated striped bass spawning locations in the Red River based on staged eggs from three sampling sites (n=77).

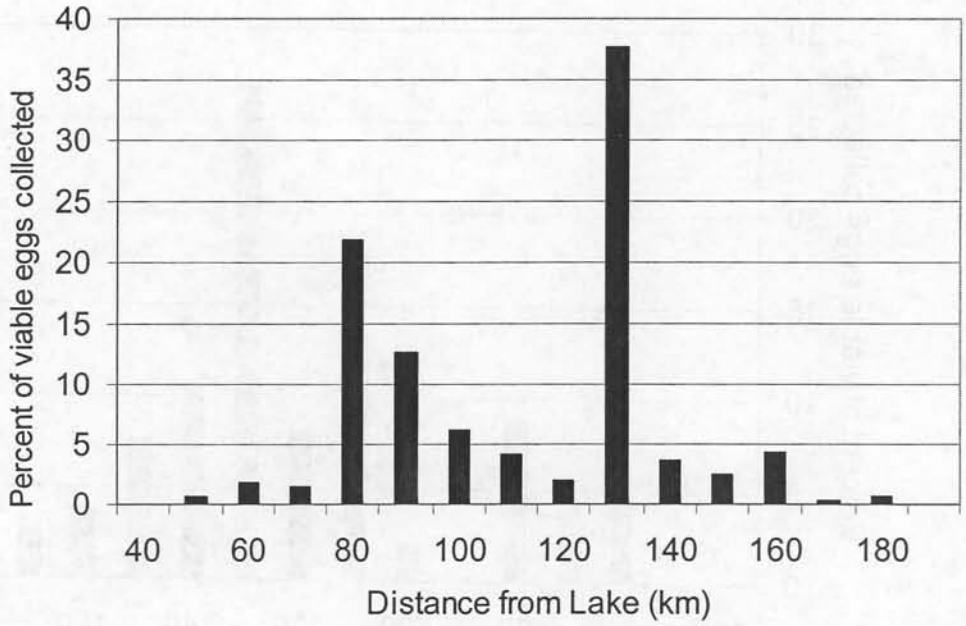

Figure 15. Distribution of 2004 estimated striped bass spawning locations in the Red River based on staged eggs from three sampling sites (n=6,145).

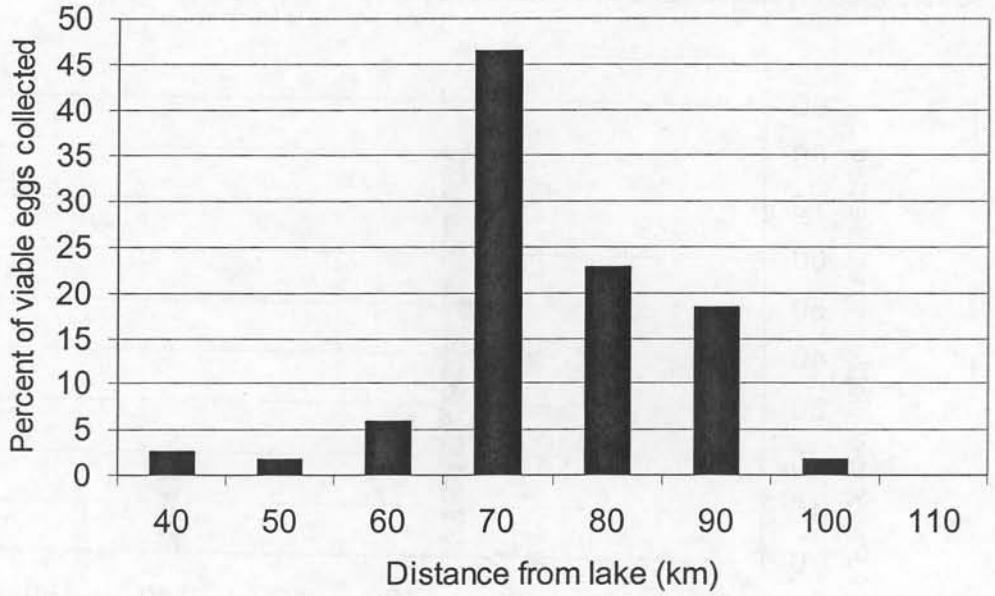

Figure 16. Distribution of 2002 estimated striped bass spawning locations in the Washita River based on staged eggs from three sampling sites (n=17,484).

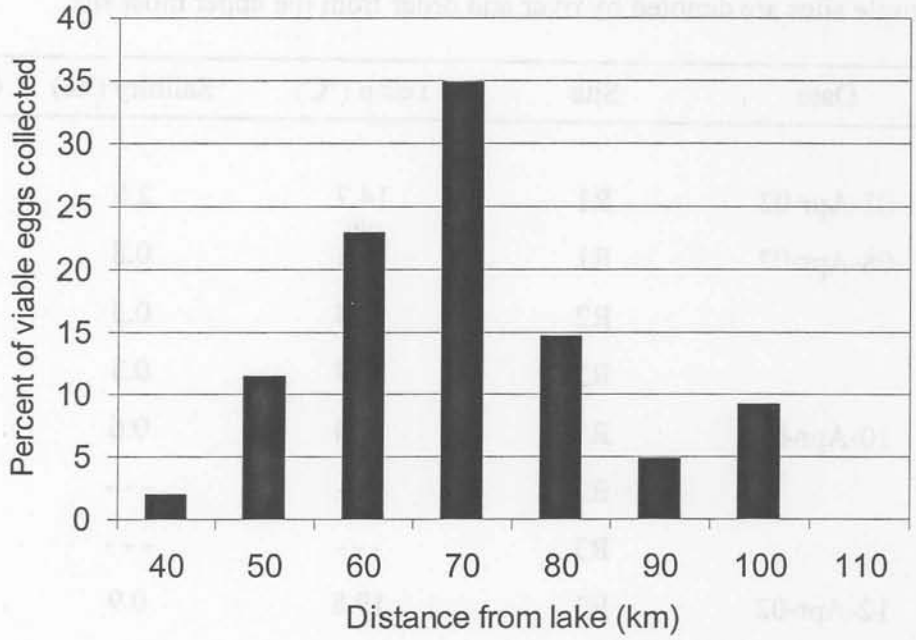

Figure 17. Distribution of 2003 estimated striped bass spawning locations in the Washita River based on staged eggs from three sampling sites (n=13,132).

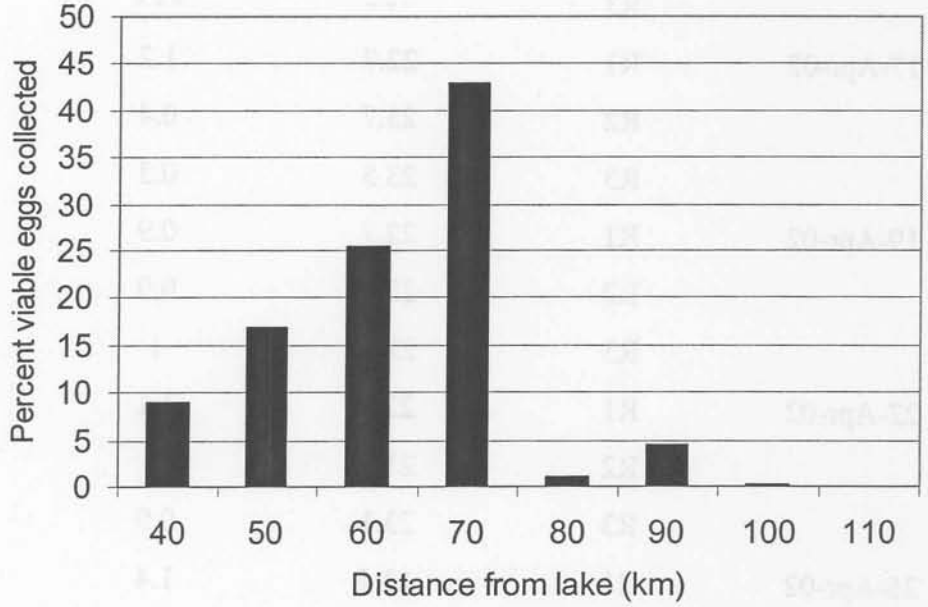

Figure 18. Distribution of 2004 estimated striped bass spawning locations in the Washita River based on staged eggs from three sampling sites (n=11,805).

Appendix I. Water chemistry parameters for the Red River samples, 2002. Standard sample sites are denoted by river and order from the upper most site.

Date	Site	Temp (°C)	Salinity (‰)	Conductivity (µs)
03-Apr-02	R1	14.7	2.8	5004
08-Apr-02	R1	14.1	0.8	1640
	R2	13.4	0.5	1008
	R3	14.7	0.3	640
10-Apr-02	R1	16.3	0.6	1170
	R2	- - -	- - -	- - -
	R3	- - -	- - -	- - -
12-Apr-02	R1	19.8	0.9	1730
	R2	20.1	0.5	1010
	R3	20.1	0.4	850
15-Apr-02	R1	22.8	0.4	750
	R2	- - -	- - -	- - -
	R3	- - -	- - -	- - -
17-Apr-02	R1	22.7	1.2	2370
	R2	23.7	0.4	870
	R3	23.5	0.3	680
19-Apr-02	R1	22.7	0.9	1790
	R2	23.1	0.9	1820
	R3	22.8	1	1940
22-Apr-02	R1	22.3	1.1	2180
	R2	21.7	1	1950
	R3	23.1	0.9	1700
26-Apr-02	R1	13.4	1.4	2820
	R2	16	1.9	3680
	R3	16.8	1.7	3210
30-Apr-02	R1	- - -	- - -	- - -

	R(km110.6)	22.5	0.9	1860
	R2	25.1	0.9	1810
	R3	---	---	---
01-May-02	R1	---	---	---
	R2	---	---	---
	R3	23.8	0.9	1760
03-May-02	R1	19.2	1.8	3470
	R2	20.1	1.5	3000
	R3	20.9	1.2	2420
05-May-02	---	---	---	---
	---	---	---	---
	---	---	---	---
07-May-02	R1	---	---	---
	R2	23.5	2.23	4270
	R3	---	---	---
10-May-02	R1	21.3	3.4	6190
	R2	22.4	2.8	5210
	R3	---	---	---

Appendix II. Water chemistry parameters for the Washita River samples, 2002. Standard sample sites are denoted by river and order from the upper most site

Date	Site	Temp (°C)	Salinity (‰)	Conductivity (µs)
03-Apr-02	W2	16.7	0.50	980
	W3	14.8	0.60	1160
09-Apr-02	W1	18.7	0.20	460
	W2	16.9	0.20	400
	W3	20	0.20	360
11-Apr-02	W1	---	---	---
	W2	---	---	---

	W3	---	---	---
13-Apr-02	W1	---	---	---
	W2	---	---	---
	W3	---	---	---
16-Apr-02	W1	---	---	---
	W2	---	---	---
	W3	---	---	---
18-Apr-02	W1	21.2	0.40	830
	W2	21.5	0.30	680
	W3	22.1	0.30	620
20-Apr-02	W1	21.8	0.30	700
	W2	21.9	0.30	710
	W3	22.1	0.30	720
23-Apr-02	W1	20.8	0.40	800
	W2	22.5	0.40	770
	W3	22.2	0.40	750
25-Apr-02	W1	---	---	---
	W2	19	0.4	810
	W3	---	---	---
27-Apr-02	W1	14.5	0.50	1100
	W2	14.5	0.40	820
	W3	14.9	0.30	560
29-Apr-02	W1	21.3	0.50	1000
	W2	21.6	0.40	930
	W3	21.8	0.40	900
02-May-02	W1	22	0.50	1030
	W2	22.4	0.50	980
	W3	23.3	0.50	960
04-May-02	W1	18.5	0.60	1220

	W2	18	0.50	1070
	W3	18.3	0.50	1030
06-May-02	W1	25.3	0.60	1260
	W2	25.9	0.60	1190
	W3	25.6	0.60	1150
09-May-02	W1	2.7	0.70	1440
	W2	23.6	0.60	1300
	W3	23.2	0.60	1240

Appendix III. Water chemistry parameters for the Red River samples, 2003. Standard sample sites are denoted by river and order from the upper most site.

Date	Site	Temp (°C)	Salinity (‰)	Conductivity (µs)
07-Apr-03	R1	15.2	3.9	7320
	R2	15.2	3.9	7320
	R3	17.3	3.0	5600
09-Apr-03	R1	9.6	3.8	7140
	R2	12.2	3.7	7000
	R3	13.2	3.2	5940
11-Apr-03	R1	15.8	3.8	7040
	R2	17.3	3.6	6670
	R3	19.8	3.4	6210
14-Apr-03	R1	19.6	3.8	6990
	R2	19.6	3.8	6870
	R3	22.0	3.1	5740
16-Apr-03	R1	17.5	3.7	6980
	R2	19.4	3.4	6190
	R3	21.3	3.2	5950
18-Apr-03	R1	21.7	3.6	6630
	R2	21.3	3.4	6300

	R3	22.7	3.0	5690
21-Apr-03	R1	17.2	3.6	6620
	R2	18.3	3.5	6480
	R3	20.7	3.1	5670
23-Apr-03	R1	17.4	3.6	6760
	R2	17.3	2.9	5460
	R3	18.2	3.1	5890
25-Apr-03	R1	19.3	3.9	7240
	R2	21.2	3.1	5700
	R3	22.6	3.0	5540
28-Apr-03	R1	----	----	----
	R2	----	----	----
	R3	----	----	----
30-Apr-03	R1	22.9	3.2	6000
	R2	22.9	3.0	5500
	R3	24.6	3.2	5880
02-May-03	R1	21.4	3.8	7050
	R2	23.0	3.3	6100
	R3	23.7	3.1	5760
05-May-03	R1	22.8	3.9	7180
	R2	23.8	4.1	7440
	R3	24.8	3.6	6530
07-May-03	R1	23.6	3.9	7190
	R2	24.2	3.8	6880
	R3	26.1	3.6	6600
09-May-03	R1	27.0	4.0	7130
	R2	27.3	3.9	7060
	R3	29.0	3.5	6450

Appendix IV. Water chemistry parameters from the Washita River samples, 2003. Standard sample sites are denoted by river and order from the upper most site.

Date	Site	Temp (°C)	Salinity (‰)	Conduct (µs)
01-Apr-03	W1	----	----	----
	W2	18.7	0.6	1230
	W3	----	----	----
08-Apr-03	W1	13.1	0.8	1680
	W2	15.4	0.7	1440
	W3	14.8	0.7	1330
10-Apr-03	W1	15.5	0.9	1790
	W2	15.4	0.8	1640
	W3	16.5	0.8	1580
12-Apr-03	W1	20.1	0.8	1620
	W2	19.5	0.9	1780
	W3	19.7	0.9	1750
15-Apr-03	W1	20.7	0.8	1700
	W2	21.3	0.9	1850
	W3	21.3	0.8	1600
17-Apr-03	W1	17.9	0.9	1770
	W2	19.0	0.8	1650
	W3	17.4	0.8	1600
19-Apr-03	W1	20.7	0.8	1600
	W2	21.1	0.9	1700
	W3	21.2	0.8	1650
22-Apr-03	W1	21.2	0.9	1790
	W2	21.0	0.9	1700
	W3	21.6	0.9	1710
24-Apr-03	W1	20.5	0.8	1690
	W2	21.4	0.8	1630
	W3	20.2	0.8	1620
26-Apr-03	W1	18.4	0.6	1250

	W2	19.2	0.6	1210
	W3	18.9	0.6	1300
29-Apr-03	W1	22.7	0.8	1560
	W2	23.9	0.7	1480
	W3	24.5	0.7	1420
01-May-03	W1	27.4	0.9	1780
	W2	27.8	0.7	1480
	W3	26.3	0.7	1460
03-May-03	W1	22.2	0.9	1820
	W2	22.5	0.8	1610
	W3	23.0	0.8	1540
06-May-03	W1	25.6	1.0	2030
	W2	26.7	0.9	1800
	W3	26.7	0.9	1720
08-May-03	W1	25.8	0.8	1548
	W2	26.1	0.8	1600
	W3	26.1	0.8	1590

Appendix V. Water chemistry parameters from the Red River samples, 2004. Standard sample sites are denoted by river and order from the upper most site.

Date	Site	Temp (°C)	Salinity (‰)	Conductivity (µs)
05-Apr-04	R1	17.6	3.9	7240
	R2	18.8	3.7	6680
	R3	-----	-----	-----
07-Apr-04	R1	17	4	7210
	R2	17	4	6920
	R3	18	4	6530
09-Apr-04	R1	21	3	6210
	R2	21	3	5430

	R3	22	3	6160
12-Apr-04	R1	13	2.1	4010
	R2	14.3	2	3760
	R3	15.2	2.9	5570
14-Apr-04	R1	14.6	3.3	6080
	R2	14.7	2.3	4400
	R3	16.7	2	3750
16-Apr-04	R1	21.1	5.1	9400
	R2	20.5	4.4	7910
	R3	21.4	3.1	5780
19-Apr-04	R1	19.9	5.3	9570
	R2	20	6.6	11680
	R3	19.9	6.6	11820
21-Apr-04	R1	20.2	4.4	8010
	R2	21.3	4.7	8400
	R3	22.4	5.1	9210
23-Apr-04	R1	23.3	4.2	7700
	R2	23.3	4.2	7580
	R3	24.1	4.2	7600
26-Apr-04	R1	19.7	0.9	1850
	R2	20.6	1	1990
	R3	21.9	0.8	1670
28-Apr-04	R1	21.9	2.3	4390
	R2	22.3	1.4	2660
	R3	23	1	1910
30-Apr-04	R1	20.2	1.7	3230
	R2	22	2.3	4310
	R3	23.7	2.3	4350
03-May-04	R1	17	1.7	3290

	R2	17.9	0.9	1780
	R3	19.2	0.8	1510
05-May-04	R1	21.3	2.2	4080
	R2	21.8	1.8	3510
	R3	23.3	1.8	3510
07-May-04	R1	23.8	2.4	4500
	R2	23.5	2.1	3980
	R3	24.4	2	3870
10-May-04	R1	23.8	2	3720
	R2	23.5	1.9	3730
	R3	24.2	1.9	3680
12-May-04	R1	23.4	3	5620
	R2	23.1	2.2	4120
	R3	25.1	1.7	3340
14-May-04	R1	16.5	3.1	5790
	R2	17.5	3	5680
	R3	18.2	2.5	4800
17-May-04	R1	22.3	2.9	5440
	R2	22.5	2.9	5400
	R3	24.5	2.8	5140

Appendix VI. Water chemistry parameters from the Washita River samples, 2004. Standard sample sites are denoted by river and order from the upper most site.

Date	Site	Temp (°C)	Salinity (‰)	Conductivity (µs)
06-Apr-04	W1	17.50	0.9	1830
	W2	17.00	0.9	1720
	W3	17.40	0.8	1680
08-Apr-04	W1	19.00	0.8	1590
	W2	18.50	0.8	1600

	W3	18.70	0.8	1520
10-Apr-04	W1	17.20	0.7	1340
	W2	17.40	0.7	1390
	W3	18.00	0.7	1460
13-Apr-04	W1	14.10	0.8	1610
	W2	15.20	0.7	1410
	W3	15.50	0.7	1360
15-Apr-04	W1	17.40	0.9	1870
	W2	17.70	0.8	1700
	W3	18.80	0.8	1610
17-Apr-04	W1	19.50	0.8	1640
	W2	20.20	1.0	1900
	W3	21.40	0.9	1810
20-Apr-04	W1	18.50	0.8	1620
	W2	18.80	0.8	1510
	W3	18.70	0.7	1470
22-Apr-04	W1	22.30	1.0	1900
	W2	22.40	0.9	1810
	W3	22.90	0.9	1720
24-Apr-04	W1	20.10	0.9	1730
	W2	19.30	0.5	1000
	W3	20.20	0.7	1470
27-Apr-04	W1	22.00	0.8	1540
	W2	21.70	0.7	1330
	W3	22.20	0.6	1250
29-Apr-04	W1	20.90	0.9	1800
	W2	21.10	0.8	1590
	W3	21.90	0.7	1500
01-May-04	W1	16.40	0.8	1690

	W2	15.90	0.4	890
	W3	16.40	0.4	930
04-May-04	W1	20.50	0.7	1500
	W2	21.40	0.7	1340
	W3	21.80	0.6	1300
06-May-04	W1	22.70	0.9	1770
	W2	23.80	0.8	1550
	W3	24.50	0.7	1500
08-May-04	W1	23.50	0.5	1030
	W2	24.10	0.7	1330
	W3	25.00	0.8	1620
11-May-04	W1	23.70	0.6	1140
	W2	24.00	0.5	1090
	W3	24.40	0.5	1070
13-May-04	W1	25.80	0.6	1190
	W2	25.60	0.5	1110
	W3	25.40	0.5	1100
15-May-04	W1	16.60	0.6	1310
	W2	17.20	0.6	1210
	W3	17.80	0.6	1170
18-May-04	W1	25.10	0.8	1510
	W2	26.00	0.7	1370
	W3	25.50	0.6	1310

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