INFLUENCE OF STREAM DISCHARGE ON REPRODUCTIVE
SUCCESS OF A PRAIRIE STREAM FISH ASSEMBLAGE

by

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CHAPTER I

INTRODUCTION

Increased demands on water resources for agricultural, municipal, and recreational uses have led to the construction of over 50 major reservoirs on the Arkansas River and its tributaries (Limbird 1993). The construction of reservoirs alters both physical and chemical conditions in streams and rivers (Patton and Hubert 1993; Freidman et al. 1998). Prairie streams and rivers historically experienced dramatic temporal fluctuations in discharge (Cross and Moss 1987; Matthews 1987, 1988; Brown and Matthews 1995); however, reservoirs have reduced both the magnitude and variability of discharge regimes in these systems (Pflieger and Grace 1987; Patton and Hubert 1993). Associated with the prolific construction of reservoirs within the Arkansas and other river basins has been a decline in distribution and abundance of several prairie-stream fishes (Cross and Moss 1987; Pflieger and Grace 1987; Limbird 1993; Bonner and Wilde 2000). The most profound declines have occurred among species that require specific discharge conditions to complete their life cycles.

There is a distinct possibility that management actions may be required to help conserve some prairie-stream species. Presently, declines in distribution and abundance of some species are thought to be the result of reproductive failure (Cross et al. 1985; Larson 1991; Luttrell et al. 1999); however, the reproductive ecology of prairie-stream fishes, particularly cyprinids, is poorly understood (Johnston and Page 1992). Several studies have suggested a potential relationship between stream discharge and

reproduction of prairie-stream cyprinids (Moore 1944; Lehtinen and Layzer 1988; Bestgen et al. 1989; Taylor and Miller 1990). If this is indeed the case, changes in the magnitude and frequency of high discharge events during the reproductive season, as a result of reservoir construction, may be largely responsible for decreases in abundance of some species. Without a more precise understanding of the conditions necessary for successful reproduction, management actions may be rendered ineffective.

In a portion of the Canadian River in New Mexico and Texas, the native fish assemblage has maintained its historical abundance with the Arkansas River shiner Notropis girardi, peppered chub Macrhybopsis tetranema, plains minnow Hybognathus placitus, flathead chub Platygobio gracilis, and red shiner Cyprinella lutrensis collectively comprising 90% of the fish assemblage (Bonner and Wilde 2000). The red shiner historically was uncommon in this portion of the river prior to construction of Ute Reservoir in New Mexico, but has greatly increased in abundance since (Bonner and Wilde 2000). At present, this stretch of the Canadian River is the only area in which these five species still co-occur. In fact, the Arkansas River shiner and peppered chub, which are endemic to the Arkansas River basin, have disappeared throughout 80 and 90% of their respective ranges within the basin and remain common only in the Canadian River of New Mexico and Texas (Pigg 1991; Luttrell et al. 1999; Eisenhour 1999; Pigg et al. 1999; Bonner and Wilde 2000). Thus, the Canadian River provides a unique opportunity to study the reproductive ecology of the cyprinid constituents of a relatively unaltered prairie-stream fish assemblage.

This study has two main objectives. The first is to examine the influence of stream discharge on the reproductive success of a prairie-stream fish assemblage. The second is to objectively evaluate a number of current hypotheses concerning the nature of the relationship between reproduction and stream discharge. My research is presented in three main chapters. In the first (Chapter II), I describe the spawning periodicity of Arkansas River shiner, peppered chub, plains minnow, flathead chub, and red shiner in the Canadian River, Texas and how it relates to patterns of stream discharge. Using this information, I present and objectively evaluate six models designed to test multiple hypotheses relating reproductive success for these species to stream discharge. Chapter III is a description of the temporal abundance of larval fish in the Canadian River. Six models relating stream discharge to larval fish abundance are similarly evaluated in this chapter. Finally, I describe how patterns of growth of age-0 Canadian River fishes are related to the date on which they hatched (Chapter IV).

Literature Cited

- Bestgen, K. R., S. P. Platania, J. E. Brooks, and D. L. Propst. 1989. Dispersal and life history traits of Notropis girardi (Cypriniformes: Cyprinidae), introduced into the Pecos River, New Mexico. *American Midland Naturalist* 122:228-235.
- Bonner, T. H., and G. R. Wilde. 2000. Changes in the fish assemblage of the Canadian River, Texas associated with reservoir construction. *Journal of Freshwater Ecology* 15:189-198.
- Brown, A. V., and W. J. Matthews. 1995. Stream ecosystems of the central United States. Pages 89-116 in C. E. Cushing, K. W. Cummings, and G. W. Marshal, editors. *River and stream ecosystems*. Elsevier, Amsterdam, Netherlands.
- Cross, F.B., R. E. Moss, and J. T. Collins. 1985. Assessment of dewatering impacts on stream fisheries in the Arkansas and Cimarron rivers. *Kansas Fish and Game Commission Nongame Contract* 46:1-161.
- Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pages 155-165 in W. J. Matthews and D. C. Heins, editors. *Community and evolutionary ecology of North American stream fishes*. University of Oklahoma Press, Norman.
- Eisenhour, D. J. 1999. Systematics of Macrhybopsis tetranema (Cypriniformes: Cyprinidae). *Copeia* 1999:969-980.
- Friedman, J. M., W. R. Osterkamp, M. L. Scott, and G. T. Auble. 1998. Downstream effects of dams on channel geometry and bottomland vegetation: regional patterns in the Great Plains. *Wetlands* 18:619-633.
- Johnston, C. E., and L. M. Page. 1992. The evolution of complex reproductive strategies in North American minnows (Cyprinidae). Pages 600-621 in R. L. Mayden, editor. *Systematics, historical ecology, and North American freshwater fishes*. Stanford University Press, Stanford, California.
- Larson, R. D. 1991. Distribution of the Arkansas River shiner, Notropis girardi, (Pisces: Cyprinidae) and possible causes for its decline. Master's thesis, Oklahoma State University, Stillwater.
- Lehtinen, S. F., and J. B. Layzer. 1988. Reproductive cycle of the plains minnow, Hybognathus placitus (Cyprinidae), in the Cimarron River, Oklahoma. *Southwestern Naturalist* 33:27-33.

- Limbird, R. L. 1993. The Arkansas River, a changing river. Pages 81-94 in L. W. Hesse, C. B. Stalnaker, N. G. Benson, and J. R. Zuboy, editors. Restoration planning for the rivers of the Mississippi River ecosystem. National Biological Survey, Washington D.C.
- Luttrell, G. R., A. A. Echelle, W. L. Fisher, and D. J. Eisenhour. 1999. Declining status of two species of the Macrhybopsis aestivalis complex (Teleostei: Cyprinidae) in the Arkansas River basin and related effects of reservoirs as barriers to dispersal. *Copeia* 1999:981-989.
- Matthews, W. J. 1987. Physicochemical tolerance and selectivity of stream fishes as related to their geographic ranges and local distributions. Pages 111-120 in W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.
- Matthews, W. J. 1988. North American prairie streams as systems for ecological study. *North American Benthological Society* 7:387-409.
- Moore, G. A. 1944. Notes on the early life-history of Notropis girardi. *Copeia* 1944:209-214.
- Patton, T. M., and W. A. Hubert. 1993. Reservoirs on a Great Plains stream affect downstream habitat and fish assemblages. *Journal of Freshwater Ecology* 8: 279-286.
- Pflieger, W. L., and T. B. Grace. 1987. Changes in the fish fauna of the lower Missouri River, 1940-1983. Pages 166-177 in W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.
- Pigg, J. 1991. Decreasing distribution and current status of the Arkansas River shiner, Notropis girardi, in the rivers of Oklahoma and Kansas. *Proceedings of the Oklahoma Academy of Sciences* 71:5-15.
- Pigg, J., R. Gibbs, and K. K. Cunningham. 1999. Decreasing abundance of the Arkansas River shiner in the South Canadian River, Oklahoma. *Proceedings of the Oklahoma Academy of Sciences* 79:7-12.
- Taylor, C. M., and R. J. Miller. 1990. Reproductive ecology and population structure of the plains minnow, Hybognathus placitus (Pisces: Cyprinidae), in central Oklahoma. *American Midland Naturalist* 123:32-39.

CHAPTER II

INFLUENCE OF STREAM DISCHARGE ON REPRODUCTIVE SUCCESS OF A PRAIRIE-STREAM FISH ASSEMBLAGE

Introduction

Stream discharge is a primary structuring mechanism for fish assemblages in lotic ecosystems (Schlosser 1985; Poff and Allan 1995; Poff et al. 1997). The magnitude and variability of discharge influences environmental conditions such as water temperature, channel morphology, and current velocity, as well as habitat and food availability (Starrett 1951; Poff and Ward 1989; Poff et al. 1997; Friedman et al. 1998). These conditions, in turn, affect the distribution and abundance of stream fish species (Matthews 1988; Power et al. 1995; Resh et al. 1988). In most streams, the magnitude of discharge varies seasonally. Annual increases in discharge from spring rains or runoff from snowmelt are common and predictable, as are decreases in discharge during hot, dry periods. Many fish species rely on these changes in discharge as environmental cues for the initiation of reproductive activity (Moyle 2000; Marchetti and Moyle 2000). For example, John (1963) found that increased discharge stimulated reproductive activity in speckled dace Rhinichthys osculus. Similarly, Nestler et al. (1988) reported that reproductive activity of Colorado pikeminnow Ptychocheilus lucius was initiated by increases in discharge.

The reproductive biology of prairie-stream fishes, particularly cyprinid species, has been poorly studied (Johnston and Page 1992). However, among species that have

been studied, there is evidence that stream discharge may be an important determinant of reproductive success. A common reproductive strategy of prairie-stream fishes is to broadcast spawn non-adhesive semi-buoyant eggs that are kept afloat by current as they develop and disperse downstream (Moore 1944; Bottrell et al. 1964; Platania and Altenbach 1998). In the absence of adequate discharge, drifting eggs and larval fish may settle out of the current onto the substrate where they may be buried by shifting sediments and perish (Moore 1944; Platania and Altenbach 1998). Thus, it would be advantageous for species with this reproductive strategy to spawn in response to increases in stream discharge (Platania and Altenbach 1998). Likewise, given the variability of summer discharge in prairie-streams (Matthews 1988; Taylor and Miller 1990; Platania and Altenbach 1998), the ability to produce multiple clutches of eggs may be adaptive. Fishes with the capacity to spawn multiple times throughout a protracted reproductive season increase the probability that a portion of their reproductive output will result in successful production of offspring (Lambert and Ware 1984; Rinchard and Kestemont 1996). There is growing evidence that, in fact, many prairie-stream fishes are multiple spawners (e.g., Gale and Buynak 1982; Gale 1986; Taylor and Miller 1990; Bonner 2000).

Although there is general agreement that stream discharge is an important determinant of reproductive success among many prairie-stream fishes, there is considerable uncertainty as to whether stream discharge actually serves as an environmental cue for the initiation of spawning or, rather, whether discharge affects reproductive success in other ways. Some studies (Moore 1944; Bestgen et al. 1989;

Taylor and Miller 1990; Larson 1991) suggest that a direct relationship between stream discharge and reproductive activity exists, whereas others (Polvika and Matthews 1996; Bonner 2000) report no such relationship. Based on information available in the literature, I constructed six models to explain the potential relationship between stream discharge and reproductive success in prairie-stream cyprinids. Reproductive success is defined herein as the successful hatching of eggs and production of age-0 fish. The simplest model predicts that reproductive success is continuous and uniform in magnitude throughout the spawning season. This uniform model is based on histological analyses of oocyte development in Arkansas River shiner and peppered chub (Bonner 2000), which indicated that production of mature oocytes was relatively constant from May through September and was unaffected by variation in magnitude of discharge. A second model predicts that reproduction is a direct function of the magnitude of stream discharge and is based on the observations of Moore (1944), Lehtinen and Layzer (1988), Bestgen et al. (1989), and Taylor and Miller (1990) that spawning only occurred during floods. Three additional models predict that successful reproduction is directly related to discharge, but only if discharge exceeds a minimum threshold level. These models are based on the possibility that drifting eggs and very young fish require a minimum discharge for successful hatching and early survival (Moore 1944; Platania and Altenbach 1998). The minimum discharge values, $9.9 \text{ m}^3/\text{s}$ ($300 \text{ ft}^3/\text{s}$), $6.6 \text{ m}^3/\text{s}$, and $3.3 \text{ m}^3/\text{s}$ were selected based on Canadian River discharge in 1997, when discharge was at or above $9.9 \text{ m}^3/\text{s}$ during the entire reproductive season and young fish were produced on almost every day (Wilde unpublished). The two lower values ($6.6 \text{ m}^3/\text{s}$ and $3.3 \text{ m}^3/\text{s}$)

were included to try and determine a minimum threshold. A final model predicts that spawning occurs over a short period and is timed to coincide with the greatest discharge of the season as suggested by Moore (1944) and Cross et al. (1985).

Each of the six models is, essentially, a testable hypothesis:

- H1: an equal number of age-0 fish are produced on each day of the reproductive season (uniform reproduction model);
- H2: reproductive success is a function of the magnitude of stream discharge (discharge reproduction model);
- H3: reproductive success is a function of stream discharge only on dates that discharge exceeds $3.3 \text{ m}^3/\text{s}$ ($3.3 \text{ m}^3/\text{s}$ threshold model);
- H4: reproductive success is a function of stream discharge only on dates that discharge exceeds $6.6 \text{ m}^3/\text{s}$ ($6.6 \text{ m}^3/\text{s}$ threshold model);
- H5: reproductive success is a function of stream discharge only on dates that discharge exceeds $9.9 \text{ m}^3/\text{s}$ ($9.9 \text{ m}^3/\text{s}$ threshold model); and
- H6: all age-0 fish are produced on the day of the single greatest discharge during the reproductive season.

The purpose of this study is to examine the reproductive periodicity of five species of prairie-stream cyprinids and its specific relationship to stream discharge patterns. I then use this information to objectively evaluate the six models (hypotheses) concerning the nature of the relationship between reproduction and stream discharge. The fish assemblage of the Canadian River in New Mexico and Texas provides a unique opportunity to study the reproductive ecology of a prairie-stream fish assemblage

dominated by cyprinid species. Arkansas River shiner Notropis girardi, peppered chub Macrhybopsis tetranema, plains minnow Hybognathus placitus, flathead chub Platygobio gracilis, and red shiner Cyprinella lutrensis historically were widespread and abundant throughout much of the Arkansas River and its tributaries. However, as a result of extensive reservoir construction within the Arkansas River basin (Limbird 1993), a number of these species has been dramatically reduced in both distribution and abundance (Cross and Moss 1987; Larson 1991; Luttrell et al. 1999; Bonner and Wilde 2000). Four species, Arkansas River shiner, peppered chub, plains minnow and flathead chub, belong to a reproductive guild that broadcast spawns semi-buoyant non-adhesive eggs (Bottrell et al. 1964; Miller and Robison 1973; Platania and Altenbach 1998), whereas red shiners spawn adhesive demersal eggs (Pflieger 1975; Gale 1986). These five species spawn multiple batches of eggs throughout a protracted spawning season extending from May through September (Olund and Cross 1961; Farringer et al. 1979; Gould 1985; Gale 1986; Taylor and Miller 1990; Bonner 2000). At present, the only area where these species still co-occur and remain abundant is in a portion of the Canadian River in New Mexico and Texas.

Study Area

The Canadian River is a Great Plains prairie-stream characterized by sand substrate and shallow braided channels (Matthews and Hill 1980). The Canadian River is the southernmost tributary of the Arkansas River and rises on the eastern slope of the Sangre de Cristo Mountains of northeast New Mexico and southern Colorado. The river

flows generally eastward through eastern New Mexico, Texas, and Oklahoma where it discharges into the Arkansas River (Dolliver 1984; Sublette et al. 1990). The study portion of the Canadian River is approximately 218 km in length and is impounded upstream by Ute Reservoir in New Mexico and downstream by Lake Meredith in Texas (Figure 2.1). River volume is variable, despite a 38% percent reduction in mean annual discharge after impoundment of Ute Reservoir and is affected by releases from Ute Reservoir, irrigation return flows, precipitation, and discharge from a major tributary, Revuelto Creek (Bonner and Wilde 2000). Arkansas River shiner, peppered chub, plains minnow, flathead chub, and red shiner collectively comprise 90% of the fish assemblage in this portion of the Canadian River (Bonner and Wilde 2000).

Methods

I collected age-0 fish from two sites on the Canadian River (Figure 2.1). Site 1 was located at the crossing of the Canadian River and U.S. Highway 287 (Potter County, Texas). Site 2 was located at the crossing of the Canadian River and U.S. Highway 385 (Oldham County, Texas). Drift nets and small mesh seines were used to collect fish from May through September in 2000 and 2001. Collections were made bimonthly in May and September and weekly during June through August unless river conditions prevented sampling. Drift nets were approximately 1m in length and had a rectangular opening with dimensions of 0.75 m × 0.50 m. They were constructed of 1-mm mesh screening that tapered into a collection container clamped to the end of the net. At each sampling site, three nets were placed across a transect perpendicular to the channel and were held

in place by metal posts. Seines (1.2×3 m, 1-mm mesh) were used to sample all available habitat types and to sample species and developmental stages not represented in drift net samples. Drift nets were fished at one site from one hour before sunset to three hours after sunset and at the other site from three hours before sunrise to one hour after sunrise. On each sampling date the beginning site was randomly chosen so that, across dates, approximately equal numbers of evening and morning samples would be collected at each site. All samples were preserved in 95% ethanol in the field. Discharge data were obtained from USGS gauging station # 00722500 located at the downstream site. I calculated discharge for each date as a five-day running average to reduce effects of rapid increases and decreases in stream discharge on the behavior of the six hypothesized models.

Laboratory procedures

In the laboratory, fish were identified to species and total length (TL) was measured to the nearest millimeter. Otoliths were removed from a sub-sample of each species collected at each site on each date. Sub-samples were taken at haphazard; however, sub-samples were occasionally augmented by inclusion of sizes (ages) of fish that were poorly represented in the sub-sample. I used t -tests to determine whether there were any differences in length between the augmented and the entire samples. There were significant differences ($P < 0.05$) in only 2 of 100 cases (5 species $\times$ 10 dates $\times$ 2 sites) in 2000. There were no significant differences in the 100 cases (5 species $\times$ 10

dates $\times$ 2 sites) in 2001. Therefore, sub-sampled fish used for otolith analysis were representative of the total catch in both years.

Procedures for otolith preparation and counting of daily growth increments generally followed those of Miller and Storck (1982). The largest pair of otoliths, the sagittae, was removed using a dissecting microscope. One otolith was attached to a glass microscope slide with thermoplastic cement while the other one was stored for use in the event that the first one was broken or lost. Otoliths from larger juvenile specimens were ground (Taubert and Coble 1977; Barkman 1978) with fine grit sandpaper and polished to increase visibility of growth increments. Daily growth increments for all otoliths were counted independently by two readers using a compound light microscope at $40\times$ magnification. Age estimates from the two readers within ten percent of each other were considered acceptable and final daily age estimates were assigned as the mean of these two estimates. When initial readings varied by more than ten percent, a third reader counted growth increments. If the third reading fell within ten percent of one or both of the other two readings, a mean of the two closest readings was taken and a final age estimate was assigned (Miller and Storck 1982, 1984). However, if the third reading was within ten percent of the two initial readings and fell exactly between the two initial readings, the otolith was reviewed by all three readers and an age was either assigned according to the guidelines above or the otolith was excluded from further consideration. All other otoliths for which readings could not be reconciled to within ten percent were excluded. To determine spawning dates from daily age estimates, I added three days to

each final daily age estimate to allow for egg incubation and embryonic development (e.g., Moore 1944; Bottrell et al. 1964).

The diameter of each otolith was measured to the nearest 0.1 mm along the longest axis. For each year and species, I used linear regression to assess the relationship between fish length and otolith diameter and between otolith diameter and daily growth increment counts. High correlations among these variables indicate a consistent pattern of otolith growth and ring deposition. This approach has been used to validate growth increments as daily ages (Miller and Storck 1982; Powles and Warlen 1988; Joyeux et al. 2001). Length of fish was a good predictor of otolith diameter in both years and explained 77% to 91% of variation in otolith diameter among all species in 2000 and 66% to 90% in 2001 (Table 2.1). Likewise, otolith diameter was a good predictor of number of growth rings in both years and explained 75% to 96% of variation in number of growth rings among all species in 2000 and 57% to 85% in 2001 (Table 2.2). Therefore, I conclude that growth increments for these species provide reliable estimates of daily ages (Miller and Storck 1984).

Model evaluation

I compared the number of fish (from collections) spawned on each date of the reproductive season to the number of fish predicted by each model on those same dates. For the uniform model, the predicted number of each species spawned on each date was calculated as the total number of aged fish in a season divided by total number of days in the reproductive season. For the discharge model, predicted number of fish spawned on

each date was determined by dividing the discharge on each date by the sum of discharge on all dates, and then multiplying this fraction by the total number of sampled fish. Numbers of fish spawned on each date for the three threshold models were calculated by dividing discharge on each date for which it exceeded the respective threshold (i.e., 3.3, 6.6, and 9.9 m³/s) by the sum of discharge on all dates that exceeded the threshold and then multiplying that fraction by the total number of sampled fish. For all dates that discharge was below the threshold, the predicted number of fish spawned was set equal to zero. For the single-spawn model, predicted number of fish spawned on each date was determined by assuming all age-0 fish were spawned on the date of greatest discharge; on all other dates the predicted number of fish spawned was zero.

I used the Akaike Information Criterion (AIC) likelihood statistic (Akaike 1973; Sakamota et al. 1986) to determine which of the competing models best approximated the observed reproductive pattern for each species. The AIC provides an unbiased comparison of competing models with differing numbers of estimated parameters. Models are penalized for each parameter introduced by adding two times the number of parameters to the negative log-likelihood value for each model. The AIC incorporates the principle of parsimony for model selection to balance the trade-offs between over and under-fitting models to data (Zhang 1994; Burnham and Anderson 1998). For a given set of models, the model with the lowest AIC value, regardless of sign, is considered the best model for predicting the observed data (Hilborn and Mangel 1997; Burnham and Anderson 1998). Because it is possible for a model to be a poor predictor of the observed data and yet have the lowest AIC value among a given set of models, it is important to

develop and assess models founded on sound assumptions and data (Burnham and Anderson 1998).

The AIC may be biased when the number of parameters becomes large relative to the sample size (Sugiura 1978; Sakamoto et al. 1986). To correct for this, Hurvich and Tsai (1989) derived a second-order AIC denoted as AIC_c . Burnham and Anderson (1998) recommended the use of the AIC_c when the sample size divided by the number of parameters is less than 40. The models used in this study exceeded the recommended value so the AIC was used. The log-likelihood estimate of sample variance is equal to that provided by least squares when errors are normally distributed (as assumed herein). In this case, the AIC statistic can be easily calculated for a given model from sum of squares (Burnham and Anderson 1998). The sum of squares for each model was calculated by subtracting observed reproduction from predicted reproduction for each date, squaring these differences, and then summing them across all dates. When the sum of squares is used to calculate the AIC statistic, the variance must be included as an estimated parameter (Burnham and Anderson 1998). There were two estimated parameters for the uniform model, the variance and mean. There also were two estimated parameters for the discharge model, the variance and the proportion of fish spawned on each date. The three threshold models each have three parameters; the variance, a binary variable (threshold discharge of 3.3, 6.6 or 9.9 m³/s) that determines if reproduction is zero or calculated as a function of discharge on each date, and the proportion of fish spawned on each date that discharge exceeds the respective threshold. The single-spawn model has two parameters, the variance and a binary variable (for each date, either no

fish or all fish were spawned). A graphical representation of each model for the Arkansas River shiner in 2000 is shown in Figure 2.2.

Results

Canadian River discharge during the April through September reproductive season varied from 0 to 156 m³/s in 2000 (Figure 2.3). Discharge was continuous until August, when drought conditions caused discharge to cease, confining the river to a series of isolated pools for the remainder of the reproductive season. Discharge exceeded 3.3, 6.6, and 9.9 m³/s on 55, 28, and 13 days, respectively. In 2001, Canadian River discharge varied from 0 to 35 m³/s during the reproductive season. Discharge was continuous through July when drought conditions again confined the river to isolated pools. However, discharge resumed in August, prior to the end of the reproductive season. Discharge exceeded 3.3, 6.6, and 9.9 m³/s on 31, 14, and 3 days, respectively.

Successful reproduction by all species occurred from April through early July in 2000 and was almost continuous during this period (Figure 2.4). Reproduction by red shiner occurred in April and early May when discharge was low. There was a distinct increase in successful reproduction by Arkansas River shiner, peppered chub, plains minnow, and flathead chub associated with a moderate peak in discharge that occurred at the end of May. However, only peppered chub had a noticeable increase in successful reproduction during July when the greatest discharge peak occurred. No evidence of reproductive success by any species was observed from August through September when the river comprised a series of isolated pools to which fish were restricted. In 2001,

successful reproduction occurred from April through August (Figure 2.5). Reproduction was continuous except during a one month period from July to August when discharge ceased. The majority of successful reproduction by all species occurred between May and June. As observed in the previous year, peppered chub was the only species for which an increase in reproductive success was associated with the greatest discharge peak which occurred in June.

Among the six models relating discharge to reproductive success, the uniform model was the best overall predictor of observed reproduction in both years of my study (Table 2.3). The uniform model was the best predictor of reproductive success in 8 of 10 species-year combinations. The discharge model was, overall, the second best predictor of reproductive success except for Arkansas River shiner, flathead chub, and red shiner in 2001 when it was the best predictor of reproductive success. The three threshold models were poorer predictors of reproduction than either the uniform or discharge models. Of the three threshold models postulated, the 3.3 m³/s threshold model was the best predictor of reproductive success for all species in both years. The single-spawn model was the poorest predictor of reproductive success for all species in both years. Akaike Information Criterion values for the single-spawn model were substantially higher (i.e., the model was the poorest predictor of reproductive success) than those of all other models.

Discussion

Successful reproduction by all species, as evidenced by the presence of age-0 fish, occurred throughout a protracted period in both years of my study. However, in contrast with the results of Bonner (2000), who found evidence of continuous reproduction by Arkansas River shiner and peppered chub even when the river was dry and confined to isolated pools, I observed no evidence of reproductive success during these periods. Moore (1944) suggested that rainfall events and a subsequent increase in river discharge stimulated Arkansas River shiner to reproduce. He also suggested that the species might be capable of delaying reproductive activity until environmental conditions (stream discharge) were suitable for survival of offspring. Based on length-frequency distributions, Bestgen et al. (1989) suggested that an introduced population of Arkansas River shiner in the Pecos River spawned multiple times in response to increased discharge. Taylor and Miller (1990) and Lehtinen and Layzer (1988) reached a similar conclusion for the plains minnow based on length-frequencies and gonadosomatic indices. However, my study is the first to determine spawning dates for these species from otoliths and growth increments, and provides no evidence that reproduction is distinctly episodic in nature or restricted to periods of flooding. The species studied here appear to be capable of continuous reproduction, although survival of eggs and young likely depends on the magnitude of stream discharge.

Despite the apparent inability of Canadian River fishes to successfully reproduce during periods of drought, at least three of the five species studied herein are known to spawn in standing waters. Bonner (2000) found mature oocytes and spent follicles in the

ovaries of both Arkansas River shiner and peppered chub collected from isolated pools in the Canadian River, indicating that spawning had occurred in these pools. The red shiner can successfully reproduce in wading pools (Gale 1986) and aquaria (Vives 1993). Two hypotheses potentially explain the lack of successful reproduction in pools. First, water temperatures may exceed the upper threshold for survival of eggs and larval fish. Indeed, Gale (1986) observed almost complete mortality of red shiner eggs at temperatures greater than 34°C. Critical thermal maxima (CTM) have been reported for adult Arkansas River shiner (35.9°C), red shiner (36.6°C), and plains minnow (39.7°C) (Matthews 1987; Ostrand and Wilde 2001). Temperatures within pools neared lethal temperatures in both years of my study (Durham unpublished) and may have been a source of mortality for eggs and age-0 fish. Second, predation on eggs and larval fish by adults may limit, or prevent, successful reproduction in pools. Fish in isolated pools are extremely concentrated and food resources are limited (Wilde et al. 2001). Arkansas River shiner, peppered chub, and flathead chub are opportunistic feeders (Olund and Cross 1961; Wilde et al. 2001) and the red shiner is known to feed on small fish and eggs of their own as well as other species (Rupert 1993; Vives 1993; Gido et al. 1999). Individually or in combination, high water temperatures and predation by adults on eggs and larval fish may explain the inability of Canadian River fishes to successfully reproduce in pools.

Of the six hypothesized models relating reproductive success to stream discharge, the uniform model generally was the best predictor of reproductive success for all species; although in 2001 the discharge model was the best predictor of reproductive

success for the Arkansas River shiner, flathead chub, and red shiner. Among the models that specifically related reproductive success to stream discharge, the discharge model was, without exception, the best predictor of reproductive success. Although the uniform model is consistent with the observations of Bonner (2000), it is inconsistent with my observation that age-0 fish were not produced during periods of no discharge. The apparent superiority of the uniform model over the discharge model likely is the result of the way the models were parameterized and evaluated. The uniform model predicts a constant, low rate of reproductive success. The discharge model relates reproductive success to discharge; high discharge implies increased reproductive success. Comparing predicted and observed success and squaring the difference to obtain the likelihood and AIC, would favor an inferior model that was always off by a constant, relatively small amount as is the case for the uniform model. The discharge model, although a poorer predictor of reproductive success based on the AIC, is more consistent with the observations of others who have related reproduction to discharge (Moore 1944; Lehtinen and Layzer 1988; Bestgen et al. 1989; Taylor and Miller 1990; Platania and Altenbach 1998).

Discharge levels for the three threshold models were established a priori based on previous work (Wilde unpublished) that showed that Arkansas River shiner and peppered chub successfully reproduced on almost every day during the summer of 1997 when discharge in the Canadian River exceeded $9.9 \text{ m}^3/\text{s}$ ($300 \text{ ft}^3/\text{s}$) during the entire reproductive season. Thus, this level of discharge ($9.9 \text{ m}^3/\text{s}$) is sufficient for successful reproduction in the Canadian River. However, a population of Arkansas River shiner has

persisted in the Pecos River, New Mexico since 1978 where discharge has averaged 5.7 m³/s (Bestgen et al. 1989). Therefore, I included models with lower threshold discharges (6.6 m³/s and 3.3 m³/s models) in an attempt to determine the minimum threshold discharge necessary for successful reproduction. Among the three threshold models, AIC scores progressively decreased (improved) for all species in both years as the threshold level was reduced from 9.9 to 6.6 to 3.3 m³/s. The minimum necessary discharge required for successful reproduction may be lower than the 3.3 m³/s used herein.

The single-spawn model was the poorest predictor of reproductive success and should be rejected. Results of this study clearly indicate that the species studied here spawn over a protracted period of time and other studies have shown that individuals are multiple spawners, producing several clutches of eggs during the reproductive season (Gale 1986; Taylor and Miller 1990; Bonner 2000). Multiple spawning, a bet-hedging reproductive strategy to counter frequent fluctuations in environmental conditions in variable systems (Lambert 1984; Lambert and Ware 1984; Weddle and Burr 1991), is common among stream fishes. This strategy has been reported for cyprinid species in the Meuse River, Belgium (Rinchard and Kestemont 1996) and an intermittent stream in Taiwan (Wang et al. 1995). Given the relatively short lifespan (1 to 3 years) of most small cyprinids, spreading reproductive effort across a prolonged breeding season increases the chances that a portion of reproductive output for a season will survive to recruit to the population (Lambert and Ware 1984; Weddle and Burr 1991; Rinchard and Kestemont 1996).

Differences between observed reproduction and that predicted by my six models suggest considerable potential for improvement. My results suggest two specific refinements to these models. First, reproduction appears to occur almost continuously when discharge exceeds $0.06 \text{ m}^3/\text{s}$, the minimum discharge at which larval fish were spawned. Reproductive success is zero when there is no discharge. Second, most species showed no increase in reproductive success when discharge exceeded $25 \text{ m}^3/\text{s}$. From the first observation, it appears that a definitive model relating stream discharge to reproductive success will likely be a threshold model, but with perhaps a lower threshold than those considered here. There also is likely to be an upper threshold, beyond which reproduction is low, as a result of eggs and larvae being displaced too far downstream during development. For example, based on a description of egg transport in the Pecos River by Platania and Altenbach (1998), a discharge of $75 \text{ m}^3/\text{s}$ could transport eggs as far as 400 km. The Canadian River between Ute Reservoir, New Mexico and the upper reaches of Lake Meredith, Texas is only 218 km in length (Bonner and Wilde 2000). Thus, eggs spawned in the Canadian River during periods of high stream discharge could be transported into Lake Meredith where they would be subjected to predation by reservoir fishes. Finally, my results do not support a direct relationship between stream discharge and reproductive success, although one may exist. Instead, reproductive success may depend more on the persistence of discharge in the river during the entire reproductive season so that fish are not confined to pools.

Further refinement and testing of these and other models will improve our understanding of the reproductive ecology of, and determinants of reproductive success

in, prairie-stream fish assemblages. This will result in greater knowledge of the mechanisms responsible for observed declines in distribution and abundance of several species and guide potential management efforts. Recovery of populations of some species may be possible by using water releases from upstream reservoirs to augment current discharge regimes to enhance reproductive success. However, because of growing scarcity and demand for water, the precise requirements for successful reproduction must be known for management actions such as reservoir releases to be practically implemented.

Although the specific models constructed and evaluated in my study focused on clarifying the relationship between stream discharge and reproductive success by prairie-stream fishes, I believe that this approach could be useful for understanding how specific factors might influence the reproductive success of fishes inhabiting other types of systems as well. For example, a modeling approach similar to the one presented herein might be applied to the question of how spring and summer water levels affect reproductive success and recruitment for nesting reservoir species. The use of the AIC and other likelihood statistics is an efficient way to simultaneously evaluate alternative hypotheses. Rather than designing an individual experiment to test each hypothesis, a single well thought out sampling design often is sufficient to evaluate multiple hypotheses. Only recently has the AIC been used to address fisheries problems (Hilborn and Mangel 1997); however, it can provide important insights and should be considered in appropriate situations.

Literature Cited

- Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 268-281 in B. N. Petrov and F. Csaki, editors. 2nd international symposium on information theory. Publishing House of the Hungarian Academy of Sciences, Budapest. Reprinted in 1992. Pages 610-624 in S. Kotz and N. Johnson, editors. Breakthroughs in statistics. Springer-Verlag, New York.
- Barkman, R. C. 1978. The use of otolith growth rings to age young Atlantic silversides, Menidia menidia. Transactions of the American Fisheries Society 107:790-792.
- Bestgen, K. R., S. P. Platania, J. E. Brooks, and D. L. Propst. 1989. Dispersal and life history traits of Notropis girardi (Cypriniformes: Cyprinidae), introduced into the Pecos River, New Mexico. American Midland Naturalist 122:228-235.
- Bonner, T. H. 2000. Life history and reproductive ecology of the Arkansas River shiner and peppered chub in the Canadian River, Texas and New Mexico. Unpublished Ph.D. Dissertation, Texas Tech University, Lubbock.
- Bonner, T. H., and G. R. Wilde. 2000. Changes in the fish assemblage of the Canadian River, Texas associated with reservoir construction. Journal of Freshwater Ecology 15:189-198.
- Bottrell, C. E., R. H. Ingersol, and R. W. Jones. 1964. Notes on the embryology, early development, and behavior of Hybopsis aestivalis tetranemus (Gilbert). Transactions of the American Microscopical Society 83:391-399.
- Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York.
- Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pages 155-165 in W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.
- Cross, F.B., R. E. Moss, and J. T. Collins. 1985. Assessment of dewatering impacts on stream fisheries in the Arkansas and Cimarron rivers. Kansas Fish and Game Commission Nongame Contract 46:1-161.
- Dolliver, P. N. 1984. Cenozoic evolution of the Canadian River Basin. Baylor Geological Studies Bulletin No. 42. Waco, Texas.

- Farringer, R. T., A. A. Echelle, and S. F. Lehtinen. 1979. Reproductive cycle of the red shiner, Notropis lutrensis, in central Texas and south central Oklahoma. Transactions of the American Fisheries Society 108:271-276.
- Friedman, J. M., W. R. Osterkamp, M. L. Scott, and G. T. Auble. 1998. Downstream effects of dams on channel geometry and bottomland vegetation: regional patterns in the Great Plains. Wetlands 18:619-633.
- Gale, W. F. 1986. Indeterminate fecundity and spawning behavior of captive red shiners-fractional, crevice spawners. Transactions of the American Fisheries Society 115:429-437.
- Gale, W. F., and G. L. Buynak. 1982. Fecundity and spawning frequency of the fathead minnow—a fractional spawner. Transactions of the American Fisheries Society 111:35-40.
- Gido, G. B., J. F. Schaefer, K. Work, P. W. Lienesch, E. M. Matthews, and W. J. Matthews. 1999. Effects of red shiner (Cyprinella lutrensis) on Red River pupfish (Cyprinodon rubrofluvatilis). Southwestern Naturalist 44:287-295.
- Gould, W. 1985. Aspects of the biology of the flathead chub (Hybopsis gracilis) in Montana. Great Basin Naturalist 45:332-336.
- Hilborn, R., and M. Mangel. 1997. The ecological detective: confronting models with data. Princeton University Press, Princeton, New Jersey.
- Hurvich, C. M., and C. Tsai. 1989. Regression and time series model selection in small samples. Biometrika 76:297-307.
- John, K. R. 1963. The effect of torrential rains on the reproductive cycle of Rhinichthys osculus (Girard) in the Chiricahua Mountains, Arizona. Copeia 1963:286-291.
- Johnston, C. E., and L. M. Page. 1992. The evolution of complex reproductive strategies in North American minnows (Cyprinidae). Pages 600-621 in R. L. Mayden, editor. Systematics, historical ecology, and North American freshwater fishes. Stanford University Press, Stanford, California.
- Joyeux, J-C., C. Aliaume, and A. Zerbi. 2001. An alternative to validation of otolith microincrementation. Journal of Fish Biology 58:873-879.
- Lambert, T. C. 1984. Larval cohort succession in herring (Clupea harengus) and capelin (Mallotus villosus). Canadian Journal of Fisheries and Aquatic Sciences 41: 1552-1564.

- Lambert, T. C., and D. M. Ware. 1984. Reproductive strategies of demersal and pelagic spawning fish. *Canadian Journal of Fisheries and Aquatic Sciences* 41: 1565-1569.
- Larson, R. D. 1991. Distribution of the Arkansas River shiner, Notropis girardi, (Pisces: Cyprinidae) and possible causes for its decline. Master's thesis, Oklahoma State University, Stillwater.
- Lehtinen, S. F., and J. B. Layzer. 1988. Reproductive cycle of the plains minnow, Hybognathus placitus (Cyprinidae), in the Cimarron River, Oklahoma. *Southwestern Naturalist* 33:27-33.
- Limbird, R. L. 1993. The Arkansas River, a changing river. Pages 81-94 in L. W. Hesse, C. B. Stalnaker, N. G. Benson, and J. R. Zuboy, editors. *Restoration planning for the rivers of the Mississippi River ecosystem*. National Biological Survey, Washington, D.C.
- Luttrell, G. R., A. A. Echelle, W. L. Fisher, and D. J. Eisenhour. 1999. Declining status of two species of the Macrhybopsis aestivalis complex (Teleostei: Cyprinidae) in the Arkansas River basin and related effects of reservoirs as barriers to dispersal. *Copeia* 1999:981-989.
- Marchetti, M. P., and P. B. Moyle. 2000. Spatial and temporal ecology of native and introduced fish larvae in lower Putah Creek, California. *Environmental Biology of Fishes* 58:76-87.
- Matthews, W. J. 1987. Physicochemical tolerance and selectivity of stream fishes as related to their geographic ranges and local distributions. Pages 111-120 in W. J. Matthews and D. C. Heins, editors. *Community and evolutionary ecology of North American stream fishes*. University of Oklahoma Press, Norman.
- Matthews, W. J. 1988. North American prairie streams as systems for ecological study. *North American Benthological Society* 7:387-409.
- Matthews, W. J., and L. G. Hill. 1980. Habitat partitioning in the fish community of a southwestern river. *Southwestern Naturalist* 25:51-66.
- Miller, R. J., and H. W. Robison. 1973. *The fishes of Oklahoma*. Oklahoma State University Press, Stillwater.
- Miller, S. J., and T. Storck. 1982. Daily growth rings in otoliths of young-of-the-year largemouth bass. *Transactions of the American Fisheries Society* 111:527-530.

- Miller, S. J., and T. Storck. 1984. Temporal spawning distribution of largemouth bass and young-of-year growth, determined from daily otolith rings. *Transactions of the American Fisheries Society* 113:571-578.
- Moore, G. A. 1944. Notes on the early life-history of Notropis girardi. *Copeia* 1944:209-214.
- Moyle, P. B. 2000. *Inland fishes of California*, 2nd ed. University of California Press. Berkeley.
- Nesler, T. P., R. T. Muth, and A. F. Wasowicz. 1988. Evidence of baseline flow spikes as spawning cues for Colorado squawfish in the Yampa River, Colorado. *American Fisheries Society Symposium* 5:68-79.
- Olund, J. O., and F. B. Cross. 1961. Geographic variation in the North American cyprinid fish, Hybopsis gracilis. University of Kansas Publishing, Lawrence.
- Ostrand, K. G., and G. R. Wilde. 2001. Temperature, dissolved oxygen, and salinity tolerances of five prairie stream fishes and their role in explaining fish assemblage patterns. *Transactions of the American Fisheries Society* 130:742-749.
- Pflieger, W. 1975. *The fishes of Missouri*. Missouri Department of Conservation, Jefferson City.
- Platania, S. P., and C. S. Altenbach. 1998. Reproductive strategies and egg types of seven Rio Grande Basin cyprinids. *Copeia* 1998:559-569.
- Poff, N. L., and D. J. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology* 76:606-627.
- Poff, N. L., D. J. Allan, M. B. Bain, J. R. Karr, K. L. Prestegard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. *BioScience* 47:769-784.
- Poff, N. L., and J. V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1805-1817.
- Polivka, K. M., and W. J. Matthews. 1996. Habitat requirements of the Arkansas River shiner. Final Federal Aid Project E-33. Oklahoma Department of Wildlife Conservation, Oklahoma City.

- Power, M. E., A. Sun, M. Parker, W. E. Dietrich, and J. T. Wootton. 1995. Hydraulic food-chain models: an approach to the study of food-web dynamics in large rivers. *BioScience* 45:159-167.
- Powles, P. M., and S. M. Warlen. 1988. Estimation of hatch periods for yellow perch, based on otolith readings from juveniles (age-0). *American Fisheries Society Symposium* 5:60-67.
- Resh, V. H., A. V. Brown, A. P. Covich, M. E. Gurtz, H. W. Li, G. W. Minshall, S.R. Reice, A. L. Sheldon, J. B. Wallace, and R. Wissmar. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society* 7:433-455.
- Rinchard, J., and P. Kestemont. 1996. Comparative study of reproductive biology in single-and multiple-spawner cyprinid fish. I. Morphological and histological features. *Journal of Fish Biology* 49:883-894.
- Ruppert, J. B., R. T. Muth, and T. P. Nesler. 1993. Predation on fish larvae by adult red shiner, Yampa and Green rivers, Colorado. *Southwestern Naturalist* 38:397-399.
- Sakamoto, Y., M. Ishiguro, and G. Kitagawa. 1986. Akaike information statistics. KTK Scientific Publishers, Tokyo.
- Schlosser, I. J. 1985. Flow regime, juvenile abundance, and the assemblage structure of stream fishes. *Ecology* 66:1484-1490.
- Starrett, W. C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. *Ecology* 32:13-27.
- Sublette, J. E., M. D. Hatch, and M. Sublette. 1990. The fishes of New Mexico. University of New Mexico Press, Albuquerque.
- Sugiura, N. 1978. Further analysis of the data by Akaike's information criterion and the finite corrections. *Communications in Statistics. Theory and Methods* A7:13-26.
- Taubert, B., and D. W. Coble. 1977. Daily rings in otoliths of three species of Lepomis and Tilapia mossambica. *Journal of the Fisheries Research Board of Canada* 34:332-340.
- Taylor, C. M., and R. J. Miller. 1990. Reproductive ecology and population structure of the plains minnow, Hybognathus placitus (Pisces: Cyprinidae), in central Oklahoma. *American Midland Naturalist* 123:32-39.

- Vives, S. P. 1993. Choice of spawning substrate in red shiner with comments on crevice spawning in Cyprinella. *Copeia* 1993:229-232.
- Wang, J., M. Liu, and L. Fang. 1995. The reproductive biology of an endemic cyprinid, Zacco pachycephalus, in Tiawan. *Environmental Biology of Fishes* 43:135-143.
- Weddle, G. K., and B. M. Burr. 1991. Fecundity and the dynamics of multiple spawning in darters: an in-stream study of Etheostoma rafinesquei. *Copeia* 1991:419-433
- Wilde, G. R., T. H. Bonner, and P. J. Zwank. 2001. Diets of the Arkansas River shiner and peppered chub in the Canadian River, New Mexico and Texas. *Journal of Freshwater Ecology* 16:403-410.
- Zhang, P. 1994. On the choice of penalty term in generalized FPE criterion. Pages 41-49 in P. Cheeseman and R. W. Oldford, editors. *Selecting models from data*. Springer-Verlag, New York.

Table 2.1. Coefficients of determination (r^2), observed level of significance (P), and number of observations (n) for the regression of otolith diameter on total length for age-0 fish collected from the Canadian River, Texas in 2000 and 2001.

Species	2000			2001		
	<u>n</u>	<u>r</u> ²	<u>P</u>	<u>N</u>	<u>r</u> ²	<u>P</u>
Arkansas River shiner	210	0.77	< 0.001	143	0.78	< 0.001
plains minnow	190	0.90	< 0.001	112	0.90	< 0.001
peppered chub	154	0.78	< 0.001	41	0.66	< 0.001
flathead chub	22	0.91	< 0.001	44	0.80	< 0.001
red shiner	162	0.89	< 0.001	100	0.72	< 0.001

Table 2.2. Coefficients of determination ($\underline{r}^2$), observed level of significance ($\underline{P}$), and number of observations ($\underline{n}$) for the regression of number of growth increments on otolith diameter for age-0 fish collected from the Canadian River, Texas in 2000 and 2001.

Species	2000			2001		
	$\underline{n}$	$\underline{r}^2$	$\underline{P}$	$\underline{n}$	$\underline{r}^2$	$\underline{P}$
Arkansas River shiner	210	0.75	< 0.001	143	0.74	< 0.001
plains minnow	190	0.85	< 0.001	112	0.85	< 0.001
peppered chub	154	0.78	< 0.001	41	0.76	< 0.001
flathead chub	22	0.96	< 0.001	44	0.57	< 0.001
red shiner	162	0.81	< 0.001	100	0.74	< 0.001

Table 2.3. Comparison of six alternate models that predict reproductive success for prairie-stream fishes. Akaike Information Criterion (AIC) values are shown for each species in each year along with the number of estimated parameters (K). For a given species and year, the lower the AIC value is, regardless of sign, the better predictor that model is of the observed reproduction.

Model	K	Arkansas River shiner						flathead chub			red shiner		
		2000	2001	2000	2001	2000	2001	2000	2001	2000	2000	2001	2001
Uniform	2	355.7	248.7	345.4	123.4	212.7	-50.4	-241.0	-67.8	214.0	137.9		
Discharge	2	459.8	241.9	425.4	148.2	277.0	-17.7	-185.1	-74.5	343.8	134.1		
Threshold (3.3 m ³ s ⁻¹)	3	486.8	294.2	446.2	221.1	294.5	29.2	-174.1	-36.2	372.1	192.6		
Threshold (6.6 m ³ s ⁻¹)	3	547.9	409.2	502.3	335.0	339.0	69.1	-137.5	24.1	424.5	292.1		
Threshold (9.9 m ³ s ⁻¹)	3	622.0	607.8	574.5	539.7	424.1	229.8	-90.1	225.5	488.0	486.2		
Single-spawn	2	968.7	776.8	906.9	705.3	754.5	371.8	174.3	401.1	917.7	668.9

Figure 2.1. Study area and location of two collection sites on the Canadian River, Texas. Site 1 was located upstream from Lake Meredith at the crossing of the Canadian River and U.S. Highway 287 (Potter County). Site 2 was located at the crossing of the Canadian River and U.S. Highway 385 (Oldham County). Collection sites are indicated by arrows.

Figure 2.2. Six models relating temporal production of age-0 fish in the Canadian River, Texas to stream discharge throughout the spawning season. The example shown is for Arkansas River shiner in 2000. The uniform model predicts uniformly constant reproduction. The discharge model predicts that production of young is directly related to stream discharge. Threshold models also predict that production is related to discharge but only if a threshold discharge is exceeded. The single-spawn model predicts that all production occurs on the date of the greatest discharge. Observed production is indicated by the solid line and reproduction predicted by the models is indicated by the broken line.

Figure 2.3. Canadian River discharge during the 2000 and 2001 spawning seasons. Arrows indicate periods during which discharge ceased and fish were confined to isolated pools.

Figure 2.4. Reproduction by Canadian River cyprinids in relation to stream discharge in 2000. The solid line represents the magnitude of discharge. Solid circles indicate the proportion of fish spawned on that date. The arrow on each graph indicates a discharge of $9.9 \text{ m}^3/\text{s}$, the greatest magnitude of discharge used in the three threshold models.

Figure 2.5. Reproduction by Canadian River cyprinids in relation to stream discharge for 2001. The solid line represents the magnitude of discharge. Solid circles indicate percent of fish spawned on that date. The arrow on each graph indicates a discharge of $9.9 \text{ m}^3/\text{s}$, the greatest magnitude of discharge used in the three threshold models. It appears from the figure that there were a few fish spawned immediately prior to the resumption of discharge in August, however, these fish were spawned during low discharge.

CHAPTER III

TEMPORAL ABUNDANCE OF LARVAL FISH IN THE CANADIAN RIVER, TEXAS

Introduction

Many species of stream fish spawn in response to changing hydrographic conditions (John 1963; Nesler et al. 1988; Poff and Allan 1995; Robinson et al. 1998; Brouder 2001; Moyle 2000). However, the specific discharge patterns that result in spawning and successful reproduction rarely have been determined. Direct observation of the spawning behavior of many species is prevented, in part, by high turbidity during the spawning season (Moore 1944; Taylor and Miller 1990; Platania and Altenbach 1998). Therefore, attempts to elucidate specific relationships between spawning activity and river discharge have been through indirect means. For example, Moore (1944) was successful in collecting eggs of the Arkansas River shiner Notropis girardi only during periods of high discharge and suggested that this species, and possibly other prairie-stream fishes, might use summer increases in discharge as cues for the initiation of spawning. Based on length-frequency distributions, Bestgen et al. (1989) concluded that Arkansas River shiner spawned during increases in discharge. Similarly, Lehtinen and Layzer (1988) and Taylor and Miller (1990) concluded from ovarian development and gonosomatic indices that reproduction by the plains minnow Hybognathus placitus also coincided with periods of elevated discharge. However, Bonner (2000) found no such relationship for Arkansas River shiner and peppered chub Macrhybopsis tetranema.

If a relationship between stream discharge and spawning activity exists, stream discharge should serve as a predictor of reproductive activity. Indeed, Floyd et al. (1984), Schlosser (1985), and Marachetti and Moyle (2000) concluded that discharge during the reproductive season affected annual patterns of abundance of age-0 fish.

Based on the available literature, I constructed six models that relate abundance of age-0 prairie-stream fishes and, indirectly, reproductive success to stream discharge. The simplest model predicts that age-0 fish abundance is continuous and uniform in magnitude throughout the spawning season. This uniform model is based on histological analyses of ovarian development in Arkansas River shiner and peppered chub (Bonner 2000), which showed that production of mature oocytes was relatively constant from May through September and unaffected by variation in magnitude of discharge. A second model predicts that age-0 fish abundance is a direct function of the magnitude of stream discharge and is based on the observations of Moore (1944), Lehtinen and Layzer (1988), Bestgen et al. (1989), and Taylor and Miller (1990) that spawning only occurred during floods. Three additional models predict that abundance of age-0 fish is directly related to stream discharge, but only if discharge exceeds a minimum threshold level. These models are based on the observation that drifting eggs and very young fish require a minimum discharge for successful hatching and early survival (Moore 1944; Platania and Altenbach 1998). A final model predicts a single peak in abundance that occurs over a short period and is timed to coincide with the greatest discharge event of the reproductive season as suggested by Moore (1944) and Cross et al. (1985). Each of these six models is essentially a testable hypothesis.

The purpose of this study was to examine the temporal abundance of age-0 fish of five species of prairie-stream cyprinids in the Canadian River, New Mexico and Texas. I then use this information to objectively evaluate the six models (hypotheses) describing the nature of the relationship between age-0 fish abundance and stream discharge. The fish assemblage of the Canadian River provides a unique opportunity to study the reproductive ecology of a prairie-stream fish assemblage. Arkansas River shiner, peppered chub, plains minnow, flathead chub Platygobio gracilis, and red shiner Cyprinella lutrensis historically were widespread and abundant throughout much of the Arkansas River and its tributaries. However, as a result of extensive reservoir construction within the Arkansas River basin (Limbird 1993), a number of these species has been dramatically reduced in both distribution and abundance (Cross and Moss 1987; Larson 1991; Luttrell et al. 1999; Bonner and Wilde 2000). Four species, Arkansas River shiner, peppered chub, plains minnow, and flathead chub belong to a reproductive guild that broadcast spawns semi-buoyant non-adhesive eggs (Bottrell et al. 1964; Miller and Robison 1973; Platania and Altenbach 1998). In contrast, red shiners spawn adhesive eggs on gravel in riffles and pools (Minckley 1972; Pfleiger 1975), on instream vegetation (Pfleiger 1975) or in crevices (Gale 1986). These five species spawn multiple batches of eggs throughout a protracted spawning season extending from May through September (Olund and Cross 1961; Farringer et al. 1979; Gould 1985; Gale 1986; Taylor and Miller 1990; Bonner 2000). At present, the only area where these species still co-occur and remain abundant is in a portion of the Canadian River in New Mexico and Texas.

Study Area

The Canadian River is a Great Plains prairie-stream characterized by sand substrate and shallow braided channels (Matthews and Hill 1980). The Canadian River is the southernmost tributary of the Arkansas River and rises on the eastern slope of the Sangre de Cristo Mountains of northeast New Mexico and southern Colorado. The river flows generally eastward through eastern New Mexico, Texas, and Oklahoma where it discharges into the Arkansas River (Dolliver 1984; Sublette et al. 1990). The study portion of the Canadian River is approximately 218 km in length and is impounded upstream by Ute Reservoir in New Mexico and downstream by Lake Meredith in Texas (Figure 3.1). River volume is variable, despite a 38% percent reduction in mean annual discharge after impoundment of Ute Reservoir and is affected by releases from Ute Reservoir, irrigation return flows, precipitation, and discharge from a major tributary, Revuelto Creek (Bonner and Wilde 2000). Arkansas River shiner, peppered chub, plains minnow, flathead chub, and red shiner collectively comprise 90% of the fish assemblage in this portion of the Canadian River (Bonner and Wilde 2000).

Methods

I sampled age-0 fish from two sites on the Canadian River (Figure 3.1). Site 1 was located at the crossing of the Canadian River and U.S. Highway 287 (Potter County, Texas). Site 2 was located at the crossing of the Canadian River and U.S. Highway 385 (Oldham County, Texas). Drift nets were used to sample fish density from May through September in 2000 and 2001. Collections were made bimonthly in May and September

and weekly during June through August unless river conditions prevented sampling. Drift nets were approximately 1m in length and had a rectangular opening with dimensions of 0.75 m $\times$ 0.50 m. They were constructed of 1-mm mesh screening which tapered into a collection container clamped to the end of the net. At each sampling site, three nets were placed across a transect perpendicular to the channel and were held in place by metal posts. Drift nets were fished at one site from one hour before sunset to three hours after sunset and at the other site from three hours before sunrise to one hour after sunrise. On each sampling date the beginning site was randomly chosen so that, across dates, approximately equal numbers of evening and morning samples would be collected at each site. Nets were retrieved each hour and all fish caught were preserved in 95% ethanol. Nets were then reset and water depth and current velocity were recorded.

In the laboratory, fish were identified to species and total length (TL) measured to the nearest millimeter. I calculated density of age-0 fish by dividing the number of fish caught by the volume of water filtered, which was determined from net dimensions, water depth, and current velocity. I used goodness-of-fit tests to determine whether there were significant differences in total number of fish collected between different sites in the same year and same sites in different years. Discharge data were obtained from USGS gauging station # 00722500 located at the downstream site. I calculated discharge for sampling date as a five-day running average to minimize effects of rapid increases and decreases in stream discharge on the behavior of the six hypothesized models.

Model evaluation

I compared the abundance of fish (from collections) on each sampling date of the reproductive season to the number of fish predicted by each model on those same dates. For the uniform model, the abundance of each species on each sampling date was calculated as the total number of fish collected in a season divided by total number of sampling dates during the reproductive season. For the discharge model, predicted abundance on each sampling date was determined by dividing the discharge on each sampling date by the sum of discharge on all sampling dates, and then multiplying this fraction by the total number of sampled fish. Abundance of fish on each sampling date for the threshold models were calculated by dividing discharge on each sampling date for which it exceeded the respective threshold (i.e., 3.3, 6.6, and 9.9 m³/s) by the sum of discharge on all sampling dates that exceeded the threshold and then multiplying that fraction by the total number of sampled fish. For all sampling dates that discharge was below the threshold, the predicted abundance of fish was set equal to zero. For the single-spawn model, predicted abundance of fish on each sampling date was determined by assuming all age-0 fish were spawned on the date of greatest discharge; on all other sampling dates the predicted abundance of fish was set at zero.

I used the Akaike Information Criterion (AIC) likelihood statistic (Akaike 1973; Sakamota et al. 1986) to determine which of the competing models best approximated the observed abundance for each species. The AIC provides an unbiased comparison of competing models with differing numbers of estimated parameters. Models are penalized for each parameter introduced by adding two times the number of parameters to the

negative log-likelihood value for each model. The AIC incorporates the principle of parsimony for model selection to balance the trade-offs between over and under-fitting models to data (Zhang 1994; Burnham and Anderson 1998). For a given set of models, the model with the lowest AIC value, regardless of sign, is considered the best model for predicting the observed data (Hilborn and Mangel 1997; Burnham and Anderson 1998). Because it is possible for a model to be a poor predictor of the observed data and yet have the lowest AIC value among a given set of models, it is important to develop and assess models founded on sound assumptions and data (Burnham and Anderson 1998).

The AIC may be biased when the number of parameters becomes large relative to the sample size (Sugiura 1978; Sakamoto et al. 1986). To correct for this, Hurvich and Tsai (1989) derived a second-order AIC denoted as AIC_c . Burnham and Anderson (1998) recommended the use of the AIC_c when the sample size divided by the number of parameters is less than 40. Because the models used in this study failed to exceed this recommended value, the AIC_c was used. The log-likelihood estimate of sample variance is equal to that provided by least squares when errors are normally distributed (as assumed herein). In this case, the AIC statistic can be easily calculated for a given model from sum of squares (Burnham and Anderson 1998). The sum of squares for each model was calculated by subtracting observed reproduction from predicted reproduction for each date, squaring these differences, and then summing them across all dates. When the sum of squares is used to calculate the AIC statistic, the variance must be included as an estimated parameter (Burnham and Anderson 1998). There were two estimated parameters for the uniform model, the variance and mean. There also were two estimated

parameters for the discharge model, the variance and the proportion of fish collected on each sampling date. The three threshold models have three parameters; the variance, a binary variable (threshold discharge of 3.3, 6.6 or 9.9 m³/s) which determines if predicted abundance is zero or calculated as a function of discharge on each sampling date, and the proportion of fish collected on each sampling date that discharge exceeds the respective threshold. The single-spawn model has two parameters, the variance and a binary variable (for each sampling date, either no fish or all fish were spawned). A graphical representation of each model for the Arkansas River shiner in 2000 is shown in Figure 3.2.

Results

Canadian River discharge during the reproductive season varied from 0 to 156 m³/s (Figure 3.3) in 2000. Discharge was continuous until August, when drought conditions caused discharge to cease confining the river to a series of isolated pools for the remainder of the reproductive season. In 2001, Canadian River discharge varied from 0 to 35 m³/s during the reproductive season. Discharge was continuous through July when drought conditions again confined the river to isolated pools. However, discharge resumed in August prior to the end of the reproductive season.

For all species, density ranged from 0 to 10 fish/100 m³ in 2000 (Figure 3.4), and was generally low (< 2 fish/100 m³) except in June when the greatest density for all species was observed. Density was greatest for Arkansas River shiner (0 to 10 fish/100 m³) and red shiner (0-9 fish/100 m³). Density of peppered chub, plains minnow, and

flathead chub was consistently less than 3 fish/100 m³. In 2001, density ranged from 0 to 4 fish/100 m³ (Figure 3.5). Peaks in density for all species occurred on 30 May and 13 June. The peak in density that occurred on 30 May coincided with the greatest peak discharge during the reproductive season; however, the peak in density that occurred on 13 June did not coincide with an increase in stream discharge. Arkansas River shiner was the most abundant species ranging from 0 to 4 fish/100 m³, followed by the plains minnow (0-1 fish/100 m³), red shiner (0-1 fish/100 m³), and flathead chub (0-0.5 fish/100 m³). Peppered chub was absent from all collections in 2001.

Eleven species representing four families were collected during the two years of the study. In 2000, Arkansas River shiner (41%), red shiner (33%), and peppered chub (13%) comprised the majority of the total catch, followed by plains minnow (8%) and flathead chub (1%). Fathead minnow Pimephales promelas, bullhead minnow Pimephales vigilax, channel catfish Ictalurus punctatus, flathead catfish Pylodictis olivaris, plains killifish Fundulus zebrinus, and gizzard shad Dorosoma cepedianum occurred in very low numbers and collectively represented 4% of the total catch. In 2001, Arkansas River shiner (59%), plains minnow (22%), and red shiner (11%) made up the majority of the total catch. Flathead chub represented only 3% of the total catch and peppered chub was absent from all samples. Bullhead minnow, plains killifish, and gizzard shad collectively comprised 5% of the total catch.

Density of all species was greater in 2000 than in 2001 and, overall, was greater at site 1 (downstream site) than at site 2 (upstream site). The total number of fish collected in both years of the study differed significantly ($P < 0.05$) between sites in 2000 ($\underline{G} =$

27.19, $\underline{P} < 0.001$), but did not differ in 2001 ($\underline{G} = 2.61$, $\underline{P} > 0.05$). The total number of fish collected in both years of the study differed significantly at site 1 ($\underline{G} = 37.93$, $\underline{P} < 0.001$) and site 2 ($\underline{G} = 25.80$, $\underline{P} < 0.001$) across years (Figure 3.6). Reproduction may be greater during wetter years. Although in both years the river was, at times, confined to isolated pools, this occurred towards the end of the reproductive season in 2000, which may explain the greater density of age-0 fish at both sites during the first year of the study. Overall drier conditions during 2001 also may explain why differences in density were observed between sites in 2000 but not in 2001.

Among the six models I constructed to assess the relationship between age-0 fish abundance and stream discharge, the uniform model was the best predictor of observed abundance for all five species in both years (Table 3.1). The discharge model was, in all cases, the second best predictor of observed abundance. In 2000, the 3.3 m³/s threshold model was the third best predictor followed by the 6.6 m³/s threshold model. The 9.9 m³/s threshold and single-spawn models generally were the poorest predictors of observed abundance. In 2001, the single-spawn model was a better predictor of abundance than the 3.3 m³/s threshold model. However, this was due to low discharge on all sampling dates during this year. Because mean discharge only exceeded 3.3 m³/s on one sampling date, the single-spawn and 3.3 m³/s threshold models were functionally equivalent. Based on the AIC, the 3.3 m³/s threshold model was a poorer predictor of abundance because it had one additional parameter. Also, in 2001 the 6.6 and 9.9 m³/s threshold models could not be evaluated because mean discharge did not exceed 6.6 m³/s, making all threshold models functionally equivalent.

Discussion

The greatest abundance of all species occurred during June in both years.

Arkansas River shiner was the most abundant species, with a peak density in 2000 of 10 fish/100 m³. Overall, density was lower in 2001. Arkansas River shiner was again the most abundant species with a peak density of 4 fish/100 m³. For all months other than June, density was less than 2 fish/100 m³ for all species in both years of the study. Drift densities of age-0 fish reported from other streams have been substantially higher (e.g., Scott and Nielsen 1989; Harvey 1991; Brown and Coon 1994). There are three possible reasons for low densities of age-0 fish in the Canadian River. First, lower densities of age-0 fish may suggest that the Canadian River is relatively unproductive. Second, lower densities of age-0 fish may be a result of size differences between systems; however, Harvey (1991) reported that discharge in the Baron Fork River, Oklahoma, where drift densities reached over 3000 fish/100 m³, ranged from 2.5 to 6 m³/s, which is substantially less than magnitudes of discharge in the Canadian River during the reproductive season. Finally, the persistent drought conditions during the two years of my study could have led to a reduction in typical densities of age-0 fish that may be present in years with greater rainfall amounts.

Species composition and proportion of catch of age-0 fish during both years of my study generally were consistent with previous studies of adult fishes in this portion of the Canadian River. Bonner (2000) reported that over a two-year period five species, Arkansas River shiner (30%), red shiner (26%), peppered chub (14%), plains minnow (12%), and flathead chub (11%) comprised 93% of the total fish assemblage. Similarly,

Bonner and Wilde (2000) found that these five species comprised about 90% of the fish assemblage. Thus, it appears that offspring are being produced in proportion to the abundance of adult fish within this assemblage.

Significantly greater numbers of age-0 fish generally were collected at the downstream site during both years of my study. Spatial variation in abundance and reproductive condition of adult fish in the Canadian River may explain this result. Bonner (2000) found that during the reproductive season, larger fish were most abundant upstream and less abundant downstream. This pattern was less pronounced during fall and winter months. Bonner (2000) concluded that an upstream spawning migration by larger, sexually-mature individuals occurred prior to, and during, the spawning season. This conclusion supports the observations of Cross et al. (1985), who first suggested the presence of an upstream spawning migration by Arkansas River shiner in Kansas. This is consistent with the reproductive mode exhibited by these species of broadcast spawning semi-buoyant eggs that drift downstream as they develop (Moore 1944; Platania and Altenbach 1998). Fish migrating upstream to spawn as they mature provides a mechanism for individuals to continually re-colonize unoccupied upstream habitats. More importantly, however, it increases the probability that eggs have adequate distances to be transported as they develop. For example, Bonner and Wilde (2000) suggested that the 218 km of the Canadian River between Ute Reservoir and the upper reaches of Lake Meredith may approximate the distance necessary for species that spawn semi-buoyant eggs to successfully reproduce. Therefore, without some form of upstream movement, populations likely would not persist from year to year because of reproductive failure.

Of the six models that relate age-0 fish abundance to stream discharge, the uniform model was the best predictor of age-0 fish abundance for all species in both years. Among the models that specifically related abundance to stream discharge, the discharge model was, without exception, the best predictor of abundance. Although the uniform model is consistent with the observations of Bonner (2000), it is inconsistent with the results of this study, which suggest that there are periods of peak abundance throughout the reproductive season. The apparent superiority of the uniform model over the discharge model likely is the result of the way the models were parameterized and evaluated. The uniform model predicts a constant, low abundance. The discharge model, however, relates abundance to discharge; high discharge implies increased abundance. Comparing predicted and observed abundance and squaring the difference to obtain the likelihood and AIC, would favor an inferior model that was always off by a constant, relatively small amount as is the case for the uniform model. Although the discharge model is a poorer predictor of abundance than the uniform model based on the AIC, it is more consistent with the observations of others who have reported a relationship between discharge and reproduction (Moore 1944; Lehtinen and Layzer 1988; Bestgen et al. 1989; Taylor and Miller 1990; Platania and Altenbach 1998).

The three threshold models and the single-spawn model were poor predictors of age-0 fish abundance. Discharge levels for the three threshold models were determined a priori based on previous work (Wilde unpublished) that showed that Arkansas River shiner and peppered chub successfully reproduced on almost every day during the summer of 1997 when discharge in the Canadian River exceeded $9.9 \text{ m}^3/\text{s}$ ($300 \text{ ft}^3/\text{s}$).

during the entire reproductive season. It appears that at least this level of discharge ($9.9 \text{ m}^3/\text{s}$) is sufficient for successful reproduction in the Canadian River. I also included two models with lower thresholds to attempt to determine a minimum threshold necessary for reproduction. Among the three threshold models in 2000, the $3.3 \text{ m}^3/\text{s}$ model was the best predictor of abundance for all species. Perhaps further reducing the $3.3 \text{ m}^3/\text{s}$ threshold would improve the performance of the threshold model approach for describing the relationship between stream discharge and reproduction. It was impossible to adequately evaluate all three threshold models in 2001 because of the low magnitude of stream discharge on all sample dates. Because there were no sample dates on which five day mean discharge exceeded $6.6 \text{ m}^3/\text{s}$, the 6.6 and $9.9 \text{ m}^3/\text{s}$ threshold models could not be evaluated. Furthermore, on only one date did discharge exceed $3.3 \text{ m}^3/\text{s}$ which resulted in the $3.3 \text{ m}^3/\text{s}$ model and the single-spawn model becoming functionally equivalent.

The single-spawn model was a poor predictor of age-0 fish abundance and should be rejected. This model predicts that total catch will occur on the sampling date after the largest discharge event during the reproductive season which is a pattern that might be expected for single-spawning species. However, a number of studies (Gale 1986; Taylor and Miller 1990; Bonner 2000; and see Chapter II) have demonstrated that these species, in fact, spawn over a protracted spawning season and produce multiple batches of eggs.

Continued refinement and testing of these and other models will improve our understanding of the role that stream discharge plays in determining the reproductive success and subsequent abundance of age-0 prairie-stream fishes. This will result in

greater knowledge of the mechanisms responsible for observed declines in distribution and abundance of several species and guide potential management efforts. Increased abundance of some species might be achieved through appropriate timing of water releases from upstream reservoirs. However, because of growing scarcity and demand for water, the precise requirements for successful reproduction must be known for management actions such as reservoir releases to be practically implemented.

Literature Cited

- Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 268-281 in B. N. Petrov and F. Csaki, editors. 2nd international symposium on information theory. Publishing House of the Hungarian Academy of Sciences, Budapest. Reprinted in 1992. Pages 610-624 in S. Kotz and N. Johnson, editors. Breakthroughs in statistics. Springer Verlag, New York.
- Bestgen, K. R., S. P. Platania, J. E. Brooks, and D.L. Propst. 1989. Dispersal and life history traits of Notropis girardi (Cypriniformes: Cyprinidae), introduced into the Pecos River, New Mexico. American Midland Naturalist 122:228-235.
- Bonner, T. H. 2000. Life history and reproductive ecology of the Arkansas River shiner and peppered chub in the Canadian River, Texas and New Mexico. Unpublished Ph.D. Dissertation, Texas Tech University, Lubbock.
- Bonner, T. H., and G. R. Wilde. 2000. Changes in the fish assemblage of the Canadian River, Texas associated with reservoir construction. Journal of Freshwater Ecology 15:189-198.
- Bottrell, C. E., R. H. Ingersol, and R. W. Jones. 1964. Notes on the embryology, early development, and behavior of Hybopsis aestivalis tetranemus (Gilbert). Transactions of the American Microscopical Society 83:391-399.
- Brouder, M. J. 2001. Effects of flooding on recruitment of roundtail chub, Gila robusta, in a southwestern river. Southwestern Naturalist 46:302-310.
- Brown, D. J. and T. G. Coon. 1994. Abundance and assemblage structure of fish larvae in the lower Missouri River and its tributaries. Transactions of the American Fisheries Society 123:718-732.
- Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference a practical information-theoretic approach. Springer-Verlag, New York.
- Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pages 155-165 in W. J. Matthews and D. C. Heins, editors. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.
- Cross, F. B., R. E. Moss, and J. T. Collins. 1985. Assessment of dewatering impacts on stream fishes in the Arkansas and Cimarron rivers. Kansas Fish and Game Commission Nongame Contract 46:1-161.

- Dolliver, P. N. 1984. Cenozoic evolution of the Canadian River Basin. Baylor Geological Studies Bulletin No. 42. Waco, Texas.
- Farringer, R. T., A. A. Echelle, and S. F. Lehtinen. 1979. Reproductive cycle of the red shiner, Notropis lutrensis, in central Texas and south central Oklahoma. Transactions of the American Fisheries Society 108:271-276.
- Floyd, K. B., R. D. Hoyt, and S. Timbrook. 1984. Chronology of appearance and habitat partitioning by stream larval fishes. Transactions of the American Fisheries Society 113:217-223.
- Gale, W. F. 1986. Indeterminate fecundity and spawning behavior of captive red shiners-fractional, crevice spawners. Transactions of the American Fisheries Society 115:429-437.
- Gould, W. 1985. Aspects of the biology of the flathead chub (Hybopsis gracilis) in Montana. Great Basin Naturalist 45:332-336.
- Harvey, B. C. 1991. Interaction of abiotic and biotic factors influence larval fish survival in an Oklahoma stream. Canadian Journal of Fisheries and Aquatic Sciences 48:1476-1480.
- Hilborn, R., and M. Mangel. 1997. The ecological detective: confronting models with data. Princeton University Press, Princeton, New Jersey.
- Hurvich, C. M., and C. Tsai. 1989. Regression and time series model selection in small samples. Biometrika 76:297-307.
- John, K. R. 1963. The effect of torrential rains on the reproductive cycle of Rhinichthys osculus (Girard) in the Chiricahua Mountains, Arizona. Copeia 1963:286-291.
- Larson, R. D. 1991. Distribution of the Arkansas River shiner, Notropis girardi, (Pisces: Cyprinidae) and possible causes for its decline. Master's thesis, Oklahoma State University, Stillwater.
- Lehtinen, S. F., and J. B. Layzer. 1988. Reproductive cycle of the plains minnow, Hybognathus placitus (Cyprinidae), in the Cimarron River, Oklahoma. Southwestern Naturalist 33:27-33.
- Limbird, R. L. 1993. The Arkansas River, a changing river. Pages 81-94 in L. W. Hesse, C. B. Stalnaker, N. G. Benson, and J. R. Zuboy, editors. Restoration planning for the rivers of the Mississippi River ecosystem. National Biological Survey, Washington, D.C.

- Luttrell, G. R., A. A. Echelle, W. L. Fisher, and D. J. Eisenhour. 1999. Declining status of two species of the Macrhybopsis aestivalis complex (Teleostei: Cyprinidae) in the Arkansas River basin and related effects of reservoirs as barriers to dispersal. *Copeia* 1999:981-989.
- Marchetti, M. P., and P. B. Moyle. 2000. Spatial and temporal ecology of native and introduced fish larvae in lower Putah Creek, California. *Environmental Biology of Fishes* 58:76-87.
- Matthews, W. J., and L. G. Hill. 1980. Habitat partitioning in the fish community of a southwestern river. *Southwestern Naturalist* 25:51-66.
- Miller, R. J., and H. W. Robison. 1973. The fishes of Oklahoma. Oklahoma State University Press. Stillwater.
- Minckley, W. L. 1972. Notes on the spawning behavior of red shiner, introduced into Burro Creek, Arizona. *Southwestern Naturalist* 17:101-103.
- Moore, G. A. 1944. Notes on the early life-history of Notropis girardi. *Copeia* 1944:209-214.
- Moyle, P. B. 2000. Inland fishes of California, 2nd ed. University of California Press. Berkeley.
- Nesler, T. P., R. T. Muth, and A. F. Wasowicz. 1988. Evidence of baseline flow spikes as spawning cues for Colorado squawfish in the Yampa River, Colorado. *American Fisheries Society Symposium* 5:68-79.
- Olund, J. O., and F. B. Cross. 1961. Geographic variation in the North American cyprinid fish, Hybopsis gracilis. University of Kansas Publishing. Museum of Natural History.
- Pflieger, W. L. 1975. The fishes of Missouri. Missouri Department of Conservation, Jefferson City.
- Platania, S. P., and C. S. Altenbach. 1998. Reproductive strategies and egg types of seven Rio Grande Basin cyprinids. *Copeia* 1998:559-569.
- Poff, N. L., and D. J. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology* 76:606-627.
- Reisen, W. K. 1972. The influence of organic drift on the food habits and life history of the yellowfin shiner, Notropis lutipinnis (Jordan and Brayton). *American Midland Naturalist* 88:376-383.

- Robinson, A. T., R. W. Clarkson, and R. E. Forrest. 1998. Dispersal of larval fishes in a regulated river tributary. *Transactions of the American Fisheries Society* 127:772-786.
- Sakamoto, Y., M. Ishiguro, and G. Kitagawa. 1986. *Akaike Information Statistics*. KTK Scientific Publishers, Tokyo.
- Schlosser, I. J. 1985. Flow regime, juvenile abundance, and the assemblage structure of stream fishes. *Ecology* 66:1484-1490.
- Scott, M. T., and L. A. Nielsen. 1989. Young fish distribution in backwaters and main-channel borders of the Kanawha River, West Virginia. *Journal of Fish Biology* 35 (Supplement A):21-27.
- Sublette, J. E., M. D. Hatch, and M. Sublette. 1990. *The fishes of New Mexico*. University of New Mexico Press, Albuquerque.
- Sugiura, N. 1978. Further analysis of the data by Akaike's information criterion and the finite corrections. *Communications in Statistics, Theory and Methods* A7:13-26.
- Taylor, C. M., and R. J. Miller. 1990. Reproductive ecology and population structure of the plains minnow, Hybognathus placitus (Pices: Cyprinidae), in central Oklahoma. *American Midland Naturalist* 123:32-39.
- Zhang, P. 1994. On the choice of penalty term in generalized FPE criterion. Pages 41-49 in P. Cheeseman and R. W. Oldford, editors. *Selecting models from data*. Springer-Verlag, New York.

Table 3.1. Comparison of six alternate models that predict abundance of age-0 fish in the Canadian River, Texas. Akaike Information Criterion (AIC) values are shown for each species in each year along with the number of estimated parameters (K). For a given species and year, the lower the AIC value is, regardless of sign, the better predictor that model is of the observed abundance.

Model	K	Arkansas River							
		shiner		plains minnow		peppered chub		flathead chub	
		2000	2001	2000	2001	2000	2001	2000	2001
Uniform	2	-34.0	-20.9	-87.5	-34.3	-66.6	*	-96.7	-45.6
Discharge	2	-25.3	-18.3	-73.1	-31.1	-53.0	*	-91.9	-43.9
Threshold (3.3 m ³ s ⁻¹)	3	-20.6	7.9	-68.2	-4.1	-48.2	*	-87.7	-18.9
Threshold (6.6 m ³ s ⁻¹)	3	-18.1	**	-64.1	**	-44.5	*	-86.2	**
Threshold (9.9 m ³ s ⁻¹)	3	-14.8	**	-59.9	**	-40.7	*	-83.8	**
Single-spawn	2	-15.2	-12.1	-59.4	-24.1	-40.6	*	-84.9	-38.9
* No peppered chub was collected in 2001.									
** Mean discharge did not exceed 6.6 m ³ /s on any sampling date in 2001. Therefore, these models were not evaluated.

Figure 3.1. Study area and location of two collection sites on the Canadian River, Texas. Site 1 was located upstream from Lake Meredith at the crossing of the Canadian River and U.S. Highway 287 (Potter County). Site 2 was located at the crossing of the Canadian River and U.S. Highway 385 (Oldham County). Collection sites are indicated by arrows.

Figure 3.2. Six models relating abundance of age-0 fish in the Canadian River, Texas to stream discharge throughout the spawning season. The example shown is for Arkansas River shiner in 2000. The uniform model predicts uniformly constant abundance. The discharge model predicts that abundance of young is directly related to stream discharge. Threshold models also predict that abundance is related to discharge but only if a threshold discharge is exceeded. The single-spawn model predicts that all fish are present only after the date of the greatest discharge. Observed abundance is indicated by the solid line and abundance predicted by the models is indicated by the broken line.

Figure 3.3. Canadian River discharge during the 2000 and 2002 spawning seasons. Arrows indicate periods during which discharge ceased and fish were confined to isolated pools.

Figure 3.4. Density of age-0 fish collected during 2000 from two sites on the Canadian River, Texas.

Figure 3.5. Density of age-0 fish collected during 2001 from two sites on the Canadian River, Texas.

Figure 3.6. Percentage of all species collected from the Canadian River, Texas during 2000 and 2001. Percentages across all species, both sites, and both years sum to 100. Species designations are: Arkansas River shiner—ARS, peppered chub—PC, plains minnow—PM, flathead chub—FHC, red shiner—RS, and several species that were present in drift samples in low numbers—Other.

CHAPTER IV

EFFECT OF HATCH DATE ON FIRST-SUMMER GROWTH OF AGE-0 PRAIRIE-STREAM CYPRINIDS

Introduction

Reproduction of most fishes is seasonal in occurrence and timed to maximize the probability that offspring will have resources necessary for growth and survival (Hontela and Stacey 1990; Cushing 1990; Conover 1992). Timing of reproduction in some fishes is strongly linked to seasonal cycles in food availability (Cushing 1975, 1990; Leggett and DeBlois 1994), whereas for others reproductive output appears to be associated with specific environmental conditions, such as temperature and photoperiod length. For example, Lowe-McConnell (1979) and Munro (1990) found that reproduction by several tropical fish species was timed to occur at the onset of the rainy season, presumably to maximize the time available to offspring for growth before the onset of the dry season.

Synchronizing reproduction with optimum conditions for growth and survival of offspring is more difficult for species that inhabit variable environments. Streams and rivers often are characterized by fluctuating physical and chemical conditions and frequent disturbance such as flood and drought. Prairie and lowland streams, in particular, have been recognized as highly variable environments and are characterized by rapid changes in discharge, temperature, pH, and dissolved oxygen (Matthews 1987, Matthews 1988). Fishes inhabiting prairie and lowland streams commonly exhibit a classic bet-hedging strategy of spreading reproductive output over an extended period.

thereby increasing the chances that a portion of the reproductive output will result in successful production of offspring (Lambert and Ware 1984; Rinchard and Kestemont 1996; Trippel et al. 1997). Because these fish spawn multiple clutches of eggs, several sizes of offspring may be present at any given time during the reproductive season. Additionally, environmental conditions may differentially affect growth of young produced at different times. Individuals resulting from spawning episodes early in the season have the advantage of a longer growing season compared to those produced later (Keast and Eadie 1984; Conover 1992; Trippel et al. 1997). Individuals spawned later in the season have a shorter first growing season and may be subject to size-selective overwinter mortality, which has been documented for a number of species (Oliver et al. 1979; Henderson et al. 1988; Post and Evans 1989; Shuter and Post 1990; Thompson et al. 1991). Thus, date of hatch and subsequent growing conditions may be critical factors for reproductive success of prairie stream fishes.

The purpose of this study was to examine first-summer growth of Arkansas River shiner Notropis girardi, peppered chub Macrhybopsis tetranema, plains minnow Hybognathus placitus, flathead chub Platygobio gracilis, and red shiner Cyprinella lutrensis, and to determine if observed rates of growth for fish from separate reproductive events are related to date of hatch. The null hypothesis underlying this investigation is that growth rates are similar for all offspring of a given species regardless of date of hatch. If this is true, individuals spawned early in the season will always obtain a greater size than individuals spawned late in season.

Study Area

The Canadian River is a Great Plains prairie stream characterized by sand substrate and shallow braided channels (Matthews and Hill 1980). The Canadian River is the southernmost tributary of the Arkansas River and rises on the eastern slope of the Sangre de Cristo Mountains of northeast New Mexico and southern Colorado. The river flows generally eastward through eastern New Mexico, Texas, and Oklahoma where it discharges into the Arkansas River (Dolliver 1984; Sublette et al. 1990). The study portion of the Canadian River is approximately 218 km in length and is impounded upstream by Ute Reservoir in New Mexico and downstream by Lake Meredith in Texas (Figure 4.1). River volume is variable, despite a 38% percent reduction in mean annual discharge after impoundment of Ute Reservoir, and is affected by releases from Ute Reservoir, irrigation return flows, precipitation, and discharge from a major tributary, Revuelto Creek (Bonner and Wilde 2000). Arkansas River shiner, peppered chub, plains minnow, flathead chub, and red shiner collectively comprise 90% of the fish assemblage in this portion of the Canadian River (Bonner and Wilde 2000).

Methods

I collected age-0 fishes from two sites on the Canadian River (Figure 4.1). Site 1 was located at the junction of U.S. Highway 287 (Potter County, Texas). Site 2 was located near the junction of U.S. Highway 385 (Oldham County, Texas). Drift nets and small mesh seines were used to collect fish from May through September in 2000 and 2001. Collections were made bimonthly in May and September and weekly during June

through August unless river conditions prevented sampling. All samples were preserved in 95% ethanol in the field.

Laboratory procedures

In the laboratory fish were identified to species and total length (TL) was measured to the nearest millimeter. I removed the largest pair of otoliths, the sagittae, using a dissecting microscope. Procedures for otolith preparation and counting of daily growth increments generally followed the methods of Miller and Storck (1982). I attached one otolith to a clear glass microscope slide with thermoplastic cement and stored the other otolith for use in the event that the first one was broken or lost. Otoliths of larger specimens were ground (Taubert and Coble 1977; Barkman 1978) with fine grit sandpaper and polished to make growth increments more visible. Daily growth increments for all otoliths were counted independently by two readers using a compound light microscope at 40× magnification. Age estimates from the two readers that were within ten percent of each other were accepted and final daily ages were assigned as the mean of these two estimates. When initial readings varied by more than ten percent, a third reader counted growth increments. If the third reading fell within ten percent of one or both of the other two readings, a mean of the two closest readings was assigned as the final age estimate (Miller and Storck 1982, 1984). However, if the third reading was within ten percent of the two initial readings and fell exactly between the two initial readings, the otolith was reviewed by all three readers and an age was either assigned according to the guidelines above or the otolith was excluded from further consideration.

All other otoliths for which readings could not be reconciled to within ten percent were excluded.

Hatch dates were determined for each fish by calculating, in days, the difference between date of collection and age of the fish (number of daily rings). The growth rate for each fish was calculated by dividing TL by age. Because growth often is non-linear in young fishes, length was adjusted for age by linear regression and $\log_{10}$ -transforming both length and age. I used multiple regression to assess the effect of length and hatch date on growth.

Results

Growth rates were highly variable for all species in both years of my study. Growth rates ranged from 0.22 to 0.83 mm/d for Arkansas River shiner, 0.26 to 0.75 mm/d for peppered chub, 0.22 to 1.0 mm/d for plains minnow, 0.25 to 0.76 mm/d for flathead chub, and 0.18 to 0.88 mm/d for red shiner (Figure 4.2). In both years, there were two distinct periods of reproduction separated by a period during which no reproduction was observed. For several species, growth rates were greater for individuals spawned in the earlier period of reproduction than those spawned during the later period.

There was a significant ($P < 0.001$) relationship between log-length and log-age in all species in both years of my study, with length explaining 46 to 86% of the variation in length (Table 4.1). The slopes of all regressions were significantly different ($P < 0.001$) from 1.0 and all intercepts were different from zero indicating that growth is not isometric; therefore, simply dividing length by age, as done above does not adequately

describe daily growth rates. Instead, regression models are a more appropriate method of determining daily growth rates (Table 4.1).

I used multiple regression to adjust the affects of age on length and then assess the effects of hatch date on growth. Multiple regression models were significant ($P < 0.001$) for Arkansas River shiner and plains minnow in 2000 and for Arkansas River shiner, peppered chub, plains minnow, and flathead chub in 2001 (Table 4.2), demonstrating that growth rates of these species were related to hatch dates. Including hatch date in these models explained an additional 1 to 11% of the variation in length. Hatch date was negatively related to growth rate in Arkansas River shiner, plains minnow, and flathead chub, indicating that individuals spawned later in the reproductive season grew at a slower rate than individuals spawned earlier in the season. There was a positive relationship between hatch date and length in peppered chub, indicating that individuals spawned later in the season grew at a greater rate than those spawned earlier.

Discussion

The five species studied here produced young throughout a protracted spawning season from April through August. Drought conditions in both years led to intermittent stream discharge that hindered reproductive success, resulting in the two distinct periods of reproduction evident for most species. For several species, date of hatch significantly affected growth rate. In all but one case (peppered chub), individuals with later hatch dates grew at a slower rate than those with earlier hatch dates. There are at least two possible explanations for the observed differences in growth between early- and late

spawned fish. First, variation in water temperature across the spawning season may differentially affect growth. Second, differences in the size of spawning adults may affect size of young at hatching and subsequent growth.

Populations of Arkansas River shiner, peppered chub, plains minnow, and flathead chub in the Canadian River are at or near the southern extent of their respective ranges (Lee et al. 1980; Lehtinen and Layzer 1988; Tibbs 1998; Eisenhour 1999; Luttrell et al. 1999). Drought conditions in the upper Canadian River basin in the latter portion of both years led to periods of reduced river discharge, ultimately resulting in periods in which the river was confined to a series of isolated pools for over a month during which water temperatures in pools reached 38°C (Durham unpublished). This temperature exceeds the reported critical thermal maxima for Arkansas River shiner (35.9°C) and red shiner (36.6°C) (Matthews 1987) and is near the reported CTM for plains minnow 39.7°C (Ostrand and Wilde 2001). Growth and survival of young fishes are related to water temperature (Pepin 1991; Houde and Zastrow 1993; Stags and Otis 1996), which may explain as much as 50% of the variation in growth and survival (Houde 1997). Although growth and survival generally are positively correlated with increased temperature, this is true only within an optimum range (Kamler 1992). When temperatures exceed the optimum, increased energetic demands can compromise growth and survival. Leach and Houde (1999) found reduced growth and survival in American shad larvae that were exposed to temperatures in excess of 25°C for at least two days. Decreased growth rates of late-spawned fishes in the Canadian River may be attributable to high temperatures, which may have resulted in a cessation of feeding (e.g., Lochmiller et al. 1989; Zale

1990) or increased metabolic demands that were not compensated for by increased food consumption (e.g., Hayward and Arnold 1996).

Greater growth of early-spawned fish in the Canadian River also may be related to body size of spawning fish, particularly of females. Bonner (2000) found that two-year-old Arkansas River shiner and peppered chub were present in collections from the Canadian River only through the end of May. Presumably, these fish spawned early in the reproductive season (late April and May) and then died. Similarly, Taylor and Miller (1990) reported that two-year-old plains minnow in the Cimarron River, Oklahoma, made up the majority of spawning population during the first half of the reproductive season. Thus, there is evidence that larger fish spawn early in the spawning season. Larger (older) fish often produce larger eggs than smaller members of the same species spawning for the first time (Kamler 1992; Chambers 1997). Because egg size is positively correlated with size of larvae at hatching in a number of species (Hislop 1988; Miller et al. 1988; Chambers 1997), an initial size advantage may be retained for some time (Rosenberg and Haugen 1982; Miranda and Muncy 1987; Chambers and Miller 1995).

Producing multiple clutches of eggs is widespread among cyprinids inhabiting environmentally variable streams and rivers where discharge, temperature, habitat, and food availability range widely. For example, white bream Blicca bjoerkna and bleak Alburnus alburnus from the River Meuse, Belgium produce multiple clutches of eggs from May to June and May through July, respectively (Rinchard and Kestemont 1996). Zacco pachycephalus, a small endemic cyprinid inhabiting intermittent streams of

Tiawan is a multiple spawning species that has two periods of reproductive activity from February through April and from July through September (Wang et al. 1995). The ability to spawn multiple times throughout a protracted reproductive season increases the probability that at least some young will be produced in each reproductive season (Weddle and Burr 1991; Rinchard and Kestemont 1996; Trippel et al. 1997). However, many prairie stream cyprinids have the potential to reproduce well into August and September (Olund and Cross 1961; Farringer et al. 1979; Gould 1985; Gale 1986; Taylor and Miller 1990; Bonner 2000) which may leave some individuals relatively little time for growth and potentially subject to overwinter mortality. The extent of size-dependent survival through the first winter for prairie stream fish is unknown. Most studies of overwinter survival of fishes have been conducted in northern waters (Conover 1992), thus the relationship between body size and overwinter survival is not well understood in populations at lower latitudes. Ultimately, the fate of slow-growing late-spawned fish is uncertain. Continued study of first-summer growth for fishes in the Canadian River and elsewhere will lead to a better knowledge of the factors that affect growth and survival of prairie stream fishes.

Literature Cited

- Barkman, R. C. The use of otolith growth rings to age young Atlantic silversides, Menidia menidia. Transactions of the American Fisheries Society 107:790-792.
- Bonner, T. H. 2000. Life history and reproductive ecology of the Arkansas River shiner and peppered chub in the Canadian River, Texas and New Mexico. Unpublished Ph.D. Dissertation, Texas Tech University, Lubbock.
- Bonner, T. H., and G. R. Wilde. 2000. Changes in the fish assemblage of the Canadian River, Texas associated with reservoir construction. Journal of Freshwater Ecology 15:189-198.
- Chambers, R. C. 1997. Environmental influences on egg and propagule sizes in marine fishes. Pages 63-102 in R. C. Chambers and E. A. Trippel, editors. Early life history and recruitment in fish populations. Chapman and Hall, London.
- Chambers, R. C., and T. J. Miller. 1995. Evaluating fish growth by means of otolith increment analysis: special properties of individual-level longitudinal data. Pages 155-176 in D. H. Secor, J. M. Dean, and S. E. Campana, editors. Recent developments in fish otolith research. University of South Carolina Press, Columbia.
- Conover, D. O. 1992. Seasonality and the scheduling of life history at different latitudes. Journal of Fish Biology 41(Supplement B):161-178.
- Cushing, D. H. 1975. Marine ecology and fisheries. Cambridge University Press, Cambridge.
- Cushing, D. H. 1990. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. Advances in Marine Biology 26:249-293.
- Dolliver, P. N. 1984. Cenozoic evolution of the Canadian River Basin. Baylor Geological Studies Bulletin No. 42. Waco, Texas.
- Eisenhour, D. J. 1999. Systematics of Macrhybopsis tetranema (Cypriniformes: Cyprinidae). Copeia 1999:969-980.
- Farringer, R. T., A. A. Echelle, and S. F. Lehtinen. 1979. Reproductive cycle of the red shiner, Notropis lutrensis, in central Texas and south central Oklahoma. Transactions of the American Fisheries Society 108:271-276.

- Gale, W. F. 1986. Indeterminate fecundity and spawning behavior of captive red shiners-fractional, crevice spawners. *Transactions of the American Fisheries Society* 115:429-437.
- Gould, W. 1985. Aspects of the biology of the flathead chub (Hybopsis gracilis) in Montana. *Great Basin Naturalist* 45:332-336.
- Hayward, R. S., and E. Arnold. 1996. Temperature dependence of maximum daily consumption in white crappie: implications for fisheries management. *Transactions of the American Fisheries Society* 125:132-138.
- Henderson, P. A., R. H. A. Holmes, and R. N. Bamber. 1988. Size-selective overwintering mortality in the sand smelt, Atherina boyeri Risso, and its role in population regulation. *Journal of Fish Biology* 33:221-233.
- Hislop, J. R. G. 1988. The influence of maternal length and age on the size and weight of the eggs and the relative fecundity of the haddock, Melanogrammus aeglefinus, in British waters. *Journal of Fish Biology* 32:923-930.
- Hontela, A., and N. E. Stacey. 1990. Cyprinidae. Pages 53-77 in A. D. Munro, A. P. Scott, and T. J. Lam, editors. *Reproductive seasonality in teleosts: environmental influences*. CRC Press, Boca Raton, Florida.
- Houde, E. D. 1997. Patterns and consequences of selective processes in teleost early life histories. Pages 173-196 in R. C. Chambers and E. A. Trippel, editors. *Early life history and recruitment in fish populations*. Chapman and Hall, London.
- Houde, E. D., and C. E. Zastrow. 1993. Ecosystem- and taxon-specific dynamic and energetics properties of fish larvae assemblages. *Bulletin of Marine Science* 53: 290-335.
- Kamler, E. 1992. *Early life history of fish: an energetics approach*. Chapman and Hall, London.
- Keast, A., and J. Eadie. 1984. Growth in the first summer of life: a comparison of nine co-occurring fish species. *Canadian Journal of Zoology* 62:1242-1250.
- Lambert, T. C., and D. M. Ware. 1984. Reproductive strategies of demersal and pelagic spawning fish. *Canadian Journal of Fisheries and Aquatic Sciences* 41:1565-1569.
- Leach, S. D., and E. D. Houde. 1999. Effects of environmental factors on survival, growth, and production of American shad larvae. *Journal of Fish Biology* 54: 767-786.

- Lee, D. S., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer Jr., editors. 1980. Atlas of North American freshwater fishes. North Carolina Biological Survey, Raleigh.
- Lehtinen, S. F., and J. B. Layzer. 1988. Reproductive cycle of the Plains minnow, Hybognathus placitus (Cyprinidae), in the Cimarron River, Oklahoma. *Southwestern Naturalist* 33:27-33.
- Leggett, W. C., and E. DeBlois. 1994. Recruitment in marine fishes: is it regulated by starvation and predation in the egg and larval stages? *Netherlands Journal of Sea Research* 32:119-134.
- Lochmiller, R. L., J. D. Wiechman, and A. V. Zale. 1989. Hematological assessment of temperature and oxygen stress in a reservoir population of striped bass (Morone saxatilis). *Comparative Biochemistry and Physiology A* 93:535-541.
- Lowe-McConnell, R. M. 1979. Ecological aspects of seasonality in fishes of tropical waters. *Symposium of the Zoological Society of London* 44:219-241.
- Luttrell, G. R., A. A. Echelle, W. L. Fisher, and D. J. Eisenhour. 1999. Declining status of two species of the Macrhybopsis aestivalis complex (Teleostei: Cyprinidae) in the Arkansas River basin and related effects of reservoirs as barriers to dispersal. *Copeia* 1999:981-989.
- Matthews, W. J. 1987. Physicochemical tolerance and selectivity of stream fishes as related to their geographic ranges and local distributions. Pages 111-120 in W. J. Matthews and D. C. Heins, editors. *Community and evolutionary ecology of North American stream fishes*. University of Oklahoma Press, Norman.
- Matthews, W. J. 1988. North American prairie streams as systems for ecological study. *North American Benthological Society* 7:387-409.
- Matthews, W. J., and L. G. Hill. 1980. Habitat partitioning in the fish community of a southwestern river. *Southwestern Naturalist* 25:51-66.
- Miller, S. J., and T. Storck. 1982. Daily growth rings in otoliths of young-of-the-year largemouth bass. *Transactions of the American Fisheries Society* 111:527-530.
- Miller, S. J., and T. Storck. 1984. Temporal spawning distribution of largemouth bass and young-of-year growth, determined from daily otolith rings. *Transactions of the American Fisheries Society* 113:571-578.

- Miller, T. J., L. B. Crowder, J. A. Rice, and E. A. Marschall. 1988. Larval size and recruitment mechanisms in fishes: toward a conceptual framework. *Canadian Journal of Fisheries and Aquatic Sciences* 45:1657-1670.
- Miranda, L. E., and R. J. Muncy. 1987. Recruitment of young-of-the-year largemouth bass in relation to size structure of the parent stock. *North American Journal of Fisheries Management* 7:131-137.
- Munro, A. D. 1990. Tropical freshwater fish. Pages 145-239 in A. D. Munro, A. P. Scott, and T. J. Lam, editors. *Reproductive seasonality in teleosts: environmental influences*. CRC Press, Boca Raton, Florida.
- Oliver, J. D., G. F. Holeton, and K. E. Chua. 1979. Overwinter mortality of fingerling smallmouth bass in relation to size, relative energy stores, and environmental temperature. *Transactions of the American Fisheries Society* 108:130-136.
- Olund, J. O., and F. B. Cross. 1961. Geographic variation in the North American cyprinid fish, Hybopsis gracilis. University of Kansas Publishing, Lawrence.
- Ostrand, K. G., and G. R. Wilde. 2001. Temperature, dissolved oxygen, and salinity tolerances of five prairie stream fishes and their role in explaining fish assemblage patterns. *Transactions of the American Fisheries Society* 130:742-749.
- Pepin, P. 1991. Effect of temperature and size on development, mortality and survival rates of the pelagic early life history stages of marine fish. *Canadian Journal of Fisheries and Aquatic Sciences* 48:503-518.
- Post, J. R., and Evans, D. O. 1989. Size-dependent overwinter mortality of young-of-the-year yellow perch (Perca flavescens): laboratory, in situ enclosure, and field experiments. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1958-1968.
- Rinchard, J., and P. Kestemont. 1996. Comparative study of reproductive biology in single-and multiple-spawner cyprinid fish. I. Morphological and histological features. *Journal of Fish Biology* 49:883-894.
- Rosenberg, A. A., and A. S. Haugen. 1982. Individual growth and size-selective mortality of larval turbot (Scophthalmus maximus) reared in enclosures. *Marine Biology* 72:73-77.
- Shuter, B. J., and J. R. Post. 1990. Climate, population viability, and the zoogeography of temperate fishes. *Transactions of the American Fisheries Society* 119:314-336.

- Staggs, M. D., and K. J. Otis. 1996. Factors affecting first-year growth of fishes in Lake Winnebago, Wisconsin. *North American Journal of Fisheries Management* 16:608-618.
- Sublette, J. E., M. D. Hatch, and M. Sublette. 1990. *The fishes of New Mexico*. University of New Mexico Press, Albuquerque.
- Taubert, B., and D. W. Coble. 1977. Daily rings in otoliths of three species of Lepomis and Tilapia mossambica. *Journal of the Fisheries Research Board of Canada* 34:332-340.
- Taylor, C. M., and R. J. Miller. 1990. Reproductive ecology and population structure of the plains minnow, Hybognathus placitus (Pisces: Cyprinidae), in central Oklahoma. *American Midland Naturalist* 123:32-39.
- Thompson, J. M., E. P. Bergersen, C. A. Carlson, and L. R. Kaeding. 1991. Role of size, condition, and lipid content in the overwinter survival of age-0 Colorado squawfish. *Transactions of the American Fisheries Society* 120:346-353.
- Tibbs, J. E. 1998. Flathead chub (Platygobio gracilis) rangewide status assessment. U.S. Fish and Wildlife Service, Region 3 Minneapolis, Minnesota.
- Trippel, E. A., O. S. Kjesbu, and P. Solemdal. 1997. Effects of adult age and size structure on reproductive output in marine fishes. Pages 31-62 in R. C. Chambers and E. A. Trippel, editors. *Early life history and recruitment in fish populations*. Chapman and Hall, London.
- Wang, J., M. Liu, and L. Fang. 1995. The reproductive biology of an endemic cyprinid, Zacco pachycephalus, in Taiwan. *Environmental Biology of Fishes* 43:135-143.
- Weddle, G. K., and B. M. Burr. 1991. Fecundity and the dynamics of multiple spawning in darters: an in-stream study of Etheostoma rafinesquei. *Copeia* 1991:419-433.
- Zale, A. V., J. D. Wiechman, R. L. Lochmiller, and J. Burroughs. 1990. Limnological conditions associated with summer mortality of striped bass in Keystone Reservoir, Oklahoma. *Transactions of the American Fisheries Society* 119:72-76.

Table 4.1. Regression models for total length of age-0 prairie-stream fish collected from the Canadian River, Texas during the 2000 and 2001 reproductive seasons.

Species	Year	Intercept	Log-age	Range of ages (d)	r^2	P	n
Arkansas River shiner	2000	0.520	0.628	14-115	0.74	< 0.001	210
	2001	0.085	0.764	13-65	0.63	< 0.001	143
peppered chub	2000	-0.142	0.876	15-100	0.86	< 0.001	154
	2001	0.016	0.821	16-60	0.67	< 0.001	41
plains minnow	2000	0.669	0.636	16-131	0.71	< 0.001	190
	2001	-0.077	0.876	14-72	0.75	< 0.001	112
flathead chub	2000	-0.191	0.905	21-99	0.86	< 0.001	22
	2001	0.354	0.664	15-70	0.61	< 0.001	44
red shiner	2000	0.347	0.672	12-128	0.81	< 0.001	162
	2001	0.994	0.467	12-100	0.46	< 0.001	100

Table 4.2. Multiple regression models for total length of age-0 prairie-stream fish collected from the Canadian River during the 2000 and 2001 reproductive seasons. Only species and years for which hatch date was a significant variable are shown.

Species	Year	Intercept	Log-age	Hatch date	R^2	P	n
Arkansas River shiner	2000	0.800	0.632	-0.002	0.75	< 0.001	210
	2001	0.275	0.797	-0.002	0.67	< 0.001	143
peppered chub	2001	0.167	0.586	0.004	0.72	< 0.001	41
plains minnow	2000	1.669	0.617	-0.006	0.76	< 0.001	190
	2001	0.501	0.856	-0.003	0.83	< 0.001	112
flathead chub	2001	0.524	0.720	-0.002	0.72	< 0.001	44

Figure 4.1. Study area and location of two collection sites on the Canadian River, Texas. Site 1 was located upstream from Lake Meredith at the crossing of the Canadian River and U.S. Highway 287 (Potter County). Site 2 was located at the crossing of the Canadian River and U.S. Highway 385 (Oldham County). Collection sites are indicated by arrows.

Figure 4.2. Summer growth rates of age-0 prairie-stream cyprinids from the Canadian River, Texas in 2000 and 2001.

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