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A life history study of the Roundnose Minnow, *Dionda episcopa*, in the middle Pecos River Valley, New Mexico.

By

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Bachelor of Science, Biology,
University of New Mexico, 1998

THESIS

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Abstract

Life history aspects of Roundnose Minnows, *Dionda episcopa*, were examined for specimens collected between 2011 and 2013 in El Rito Creek, near Santa Rosa New Mexico. A recent study examining DNA suggested that, instead of supporting a widespread population of the Roundnose Minnow, New Mexico is actually home to two evolutionarily distinct Roundnose Minnow populations. This focus of this study is on the life history attributes of what may become a newly described species of *Dionda*.

Modal class progression analysis (Bhattacharya method) documented four distinct age classes of Roundnose Minnows within El Rito Creek. Sex ratios deviated from the expected 1:1 ratio in 2011, 2012, 2013, and for the study period as a whole. In all cases, sex ratios were biased towards females.

Mean female GSI values show statistically significant peaks during 2011 and 2012, with little statistical differences among 2013 mean monthly GSI values. Water quality had little explanatory power in predicting mean female GSI values when included as dependent variables in regression models. Microscopic examination of a sub-set of female gonads documented sexually mature females as small as 34 mm standard length.

Larval specimens of Roundnose Minnow occurred in nearly every sample in which that life stage was targeted for collection. These included all 2012 collections; the only complete calendar year during the study period. The continual collection of larval fish indicates some level of year round spawning by adult Roundnose Minnow.

Because artesian discharge is the primary water source for El Rito Creek, relatively stable water temperatures and habitat conditions could be favorable to year-round spawning by Roundnose Minnow. Continuous spawning, female biased sex ratios, and female sexual maturity at a relatively small size suggest a population that has a high intrinsic rate of increase and can sustain high turnover rates.

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Chapter 1

Introduction

Within the arid and semi-tropical regions of southwestern North America, species within the genus *Dionda* (Family Cyprinidae) are commonly found in streams and spring systems (Mayden et al., 1992). In New Mexico, Roundnose Minnow, *Dionda episcopa,* was once locally abundant within the lower Pecos River Valley (Koster, 1957) and was also historically found in the Rio Grande Basin (Sublette et al., 1990). Currently, it is restricted to springs and low gradient streams in the middle and lower Pecos River Valley. It was listed as State Endangered, Group II in New Mexico, but was removed from that list in 1983 (Sublette et al., 1990). In 1991, the Natural Heritage New Mexico program assigned *Dionda episcopa* a state rank of S3 = Vulnerable (Pittenger, 2000).

Like many fish species in the arid plains region of the Southwestern United States, threats to the persistence of this species come from the fragmentation of riverine systems and over-allocation of water resources for human use. Previous studies of 49 fish taxa endemic to the North American Plains (defined as the Great and Osage Plains region) identified dewatering and flow regime degradation as two primary factors resulting in range declines of endemic fish species (Hoagstrom et al., 2011). Between 1959 and 2008, 39 of the 49 North American Plains endemic fishes have declined and two have gone extinct. Dewatering and flow regime degradation affected over 80% of these 41 species (Hoagstrom et al., 2011).

Roundnose Minnows occur in the Pecos River, El Rito Creek (a Pecos River tributary), and various local small springs, marshes and cienegas near the town of Santa Rosa, New Mexico (Sublette et al., 1990, Stephen Davenport, USFWS, pers. comm.).

Through groundwater pumping, and municipal and agricultural diversions, these habitats are also subject to seasonal flow degradation, or dewatering in the case of the Pecos River.

According to the University of New Mexico Museum of Southwestern Biology (MSB), Division of Fishes database, 376 Roundnose Minnow have been collected from the Pecos River (in Guadalupe County) since the 1981 completion of the Santa Rosa Lake Dam. Those fish were taken in 22 discrete sampling efforts over 45 years (1963−2008). Of 376 specimens, 350 were collected at the confluence of El Rito Creek and the Pecos River. During that same period, 64 Roundnose Minnow were collected from various springs and small streams within Guadalupe County. These numbers contrast sharply with the 3,122 Roundnose Minnow that were collected from El Rito Creek by researchers during 2011 and suggest that the core of the Roundnose Minnow population resides in El Rito Creek.

Discharge in the Pecos River near Santa Rosa is controlled through releases made from Santa Rosa Lake (i.e., reservoir) and no longer resembles the historical flow regime. Flow in El Rito Creek is ephemeral north of the Interstate 40 Bridge crossing in Santa Rosa. In Santa Rosa, artesian discharge from the Blue Hole sinkhole enters El Rito Creek approximately 0.5 km upstream of the NM State Route 91 Bridge crossing. Discharge from Blue Hole is 0.18 cubic meters per second (cms; 3,000 gallons per minute) and a stable 16.1°C (Chronic, 1987). Immediately downstream of the NM State Route 91 Bridge crossing, El Rito Creek flows through the Janes Wallace Memorial Park and Power Dam, a property owned by the city of Santa Rosa (Figure 1).

A decommissioned power dam at the Janes Wallace Memorial Park and Power

Dam in the city of Santa Rosa impounds El Rito Creek. Santa Rosa city officials have expressed a desire to rebuild this dam (May 2011, Ian John Serrano, retired City Manager, pers. comm.) and on at least one occasion have sought appropriations from the New Mexico State legislature for this task (Campos P. 2013, SCO 0004, State of New

Figure 1. Map of the study area (Janes Wallace Memorial Park and Power Dam) and surrounding vicinity. Red lines are the boundaries of the Janes Wallace Memorial Park and Power Dam.

Mexico 51st legislature). Reconstruction of the former power dam that now impounds El Rito Creek would likely result in the dewatering or disturbance of the existing flows and aquatic habitats and negatively impact Roundnose Minnow.

A recent study suggested that, instead of supporting a widespread population of Roundnose Minnow, New Mexico is actually home to two discrete Roundnose Minnow populations one in the middle and one in the lower Pecos River Valley (Schonhuth et al., 2012). Mitochondrial DNA (mtDNA) analysis for the complete mitochondrial cytochrome b gene (*cytb*, 1140 bp) and a mitochondrial control region (*D-loop*, ≈900 bp) showed high interlineage genetic divergence in both mtDNA regions (Schonhuth et al., 2012). This high level of divergence (*cytb*: 7.1-7.6%; *D-loop*: 8.2-8.8%) between populations in the middle and lower Pecos River valley supports their recognition as two distinct species (Schonhuth et al., 2012). While all New Mexico Roundnose Minnow are currently treated as a single species (*Dionda episcopa*) Schonhuth and her coauthors are preparing a formal species description of the Santa Rosa (middle Pecos Valley) population (R.L. Mayden, Saint Louis University, pers. comm.).

One of the first steps in the conservation of any species is a thorough understanding of its life history and life-stage specific habitat requirements. Life history studies have been used to determine spawning periodicity, fecundity, age at sexual maturity, average and maximum life spans, and sex ratios of fish populations (Kucera, 1978, Thompson, 1996 and Vila-Gispert et al., 2003). The rates of natural mortality, ability of populations to respond to exploitation, and the potential of a species to be successfully re-introduced into other habitats have also been examined through life history studies (Olaf et al., 1999 and Phillips et al., 2011). If the middle Pecos River

Valley form of Roundnose Minnow is formally described as a distinct species, its very limited geographic distribution and uncertainty in surface water supply could be sufficient reason for it to be considered for protection under State or Federal law. Information regarding the size at which Roundnose Minnow become sexually mature, population structure, and duration and magnitude of spawning events can provide insight into the resilience of Roundnose Minnow to disturbance, and how they might respond to dewatering. The influence of abiotic factors on spawning period, and duration could provide insights into the ability of Roundnose Minnow to be successfully re-established at other sites.

Herein I quantified several aspects of life history parameters for this distinct Roundnose Minnow population. Specific goals were to examine population size structure and longevity, sex ratios, timing of reproduction, and to determine minimum female size at sexual maturity. In addition, I examined the relationship between the female Gonadal Somatic Indices (GSI) and the presence of larval Roundnose Minnow, and assessed the influence of several abiotic factors on female GSI values.

Chapter 2

Methodology

Study area

All collections for this study were from the impounded section of El Rito Creek in the Janes Wallace Memorial Park and Power Dam (UTM 529489.48E, 3865182.86N to 529318.45E, 3865668.72N, 13S, NAD 1983) Santa Rosa, New Mexico (Figure 1).

Reproductive biology

Samples of Roundnose Minnow were collected from April 2011 to October 2013. Both passive (light-traps and minnow traps) and active (seines of different mesh sizes) capture techniques were used to ensure collection of multiple age classes and minimize sampling bias. A minimum of 50 specimens from each sample was selected, gill tagged, weighed, measured to the nearest 0.1 mm (SL), eviscerated, and sex determined through the examination of the gonads. Prior to weighing, fish and gonads were swiped with cotton to absorb excess fluid. The mass of fully eviscerated specimens and female gonads was determined to calculate GSI values, which is a percentage of body weight composed of gonadal tissue. Differences among mean female GSI values were determined using a one-way Analysis of Variance (ANOVA). Significant differences ($p<0.05$) were determined with a Tukey-Kramer HSD test.

Multiple water quality variables were recorded hourly between September 2011 and October 2013 using a Hydrolab® Datasonde 4a. Water quality variables (temperature, salinity, specific conductance, resistivity, and total dissolved solids) were considered explanatory variables used in an Ordinary Least-squares Multiple Regression model ($\alpha =$

0.05) with female GSI values as the dependent variable. Statistical analysis was done using JMP® version 11.0 (2011). All analysis was done using untransformed, mean monthly data.

Additional specimens collected during 2012 were used to determine the minimum size at maturity of female Roundnose Minnow. That year was chosen because it was the only year in which collections were made throughout the entire calendar year. Four collections, representing each of the seasons (Winter=February, Spring=May, Summer=July, Autumn=October) were examined for mature eggs. Determination of oocyte maturation was performed microscopically and followed Galloway and Munkittrick (2006, modified from Blazer, 2002). A mature egg was defined as being post-vitellogenic with yolk globules fused into a homogenous mass (Galloway and Munkittrick, 2006).

As female Roundnose Minnow ≥40 mm SL were known to be sexually mature (based on eggs examined during GSI determination), fish were categorized into decreasing 3 mm standard length (SL) bins beginning at 39 mm SL (i.e., 39–36, 35–32, 31–28, 27–24). A minimum of five females for each size bin was examined for mature eggs. A female was considered sexually mature if fully-yolked eggs were present; the number or proportion of mature eggs was not considered. If mature eggs were found in specimens in one size bin, fish in the next smaller size bin would be examined. Only after two consecutive decreasing size bins failed to produce females with mature eggs would the examination of females terminate. This procedure was repeated for each of the four 2012 collections examined.

Population structure

Length-frequency histograms were generated by measuring SL (mm) of all individuals captured during a sampling trip. Lengths were sorted into 1 mm bins and plotted as histograms. I used modal class progression analysis to determine the number of age classes in each collection using the Bhattacharya method with a separation index (SI) >2.0 (Bhattacharya, 1967). This analysis fits a multi-modal distribution to the data resulting in the number of age classes present (i.e. 1, 2, 3, 4 etc.), but assignment of age class is left to the researcher (i.e. mean length of 8.2 mm SL = Age-0). The separation index is a measure of separation between two adjacent modal peaks using standard deviation units. Age classes are not considered discrete unless the means are separated by at least two standard deviations (i.e. SI >2.0). All modal class progression analysis was done using FiSAT II (Version 1.2, United Nations Food and Agriculture Organization, 2005). Sex was determined for 1,752 Roundnose Minnow and the sex ratio was compared to the expected 1:1 ratio using a Chi-Square test (X^2).

For each month that sampling occurred, the smallest (pre-adult) Roundnose Minnow collected were assigned to an ontogenetic stage (i.e., protolarvae, mesolarvae, metalarvae, and juvenile) following Snyder and Muth 2004. The only exception to this was the first collection (April 2011) as larval fish were not targeted for collection during that trip. Ontogenetic staging of fish was done to compare the presence of larval fish with female GSI values.

Chapter 3

Results

Female GSI values

A total of 1,650 specimens were eviscerated and sexed for determination of female GSI values with 50 fish typically examined from each of the 32 collections. One hundred fish from the 3 June 2011 collection were examined because only one of the first 50 specimens was female. No female Roundnose Minnow were present in the second sample of 50 specimens resulting in one GSI value for 100 fish from the 3 June 2011 sample. For the remaining 31 collections, female Roundnose Minnow comprised 24–98% of fish examined ($\bar{x}$=68.8%). During the study period, mean female GSI values ranged from 2.03 in January 2012 to 8.91 in July 2011 (Figure 2).

Female GSI values exhibited distinct, and seasonally different, peaks in 2011 (July) and 2012 (March). The 2011 peak occurred during early July (8 July 2011) and was significantly higher than all except the 22 June and 1 July 2011 GSI values for 2011 ($F = 6.53$, $P < 0.0001$). The 2012 peak female GSI value occurred on 9 March 2012. This value was also significantly higher ($F= 17.90$, $P <0.0001$) than any other GSI value for that year with the exception of February and April 2012. Overall GSI values in 2013 were higher than the two preceding years but exhibited little difference among mean monthly

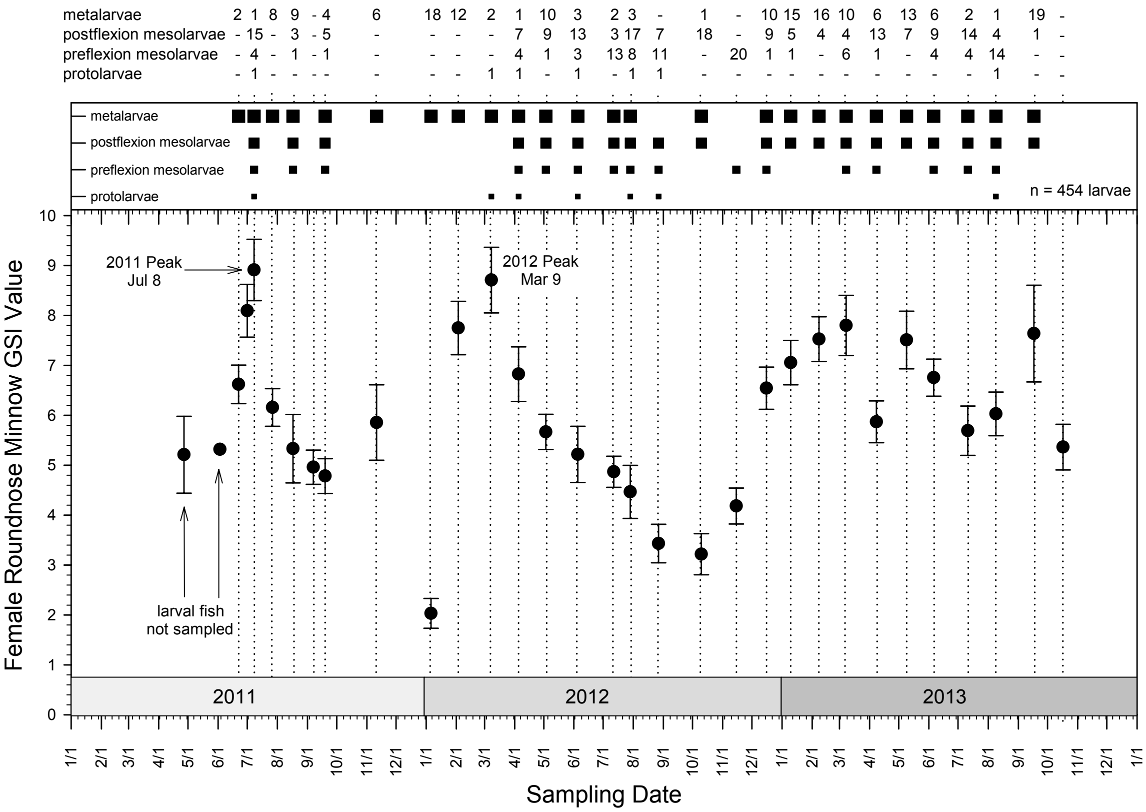

Figure 2. Mean female GSI values and larval fish collections during the sampling period (27 April 2011 – 17 October 2013). Error bars are +/- 1 standard error. Solid squares above GSI graph indicate presence of specific larval fish stage by collecting date. The number of larval individuals retained (by larval stage by date) is listed above the solid squares.

values. While the 17 October 2013 value was significantly lower than 8 February 2013 and 8 March 2013 values ($F = 3.25$, $P = 0.0008$), no other significant differences in female GSI values were present among 2013 samples.

Multiple linear regression analysis for mean female GSI values produced the following predictive equation with y equal to the predicted mean monthly female GSI value:

$$y = 24.65 - 0.18(a) + 3.94(b) + 7.59(c) - 206.54(d) - 5986.16(e)$$

where a = water temperature, b = specific conductance, c = resistivity, d = salinity, and e = total dissolved solids. This model (hence referred to as the total model) had little predictive power ($R^2 = 0.20$, $P = 0.54$) with broad lower and upper 95% confidence intervals (Figure 3).

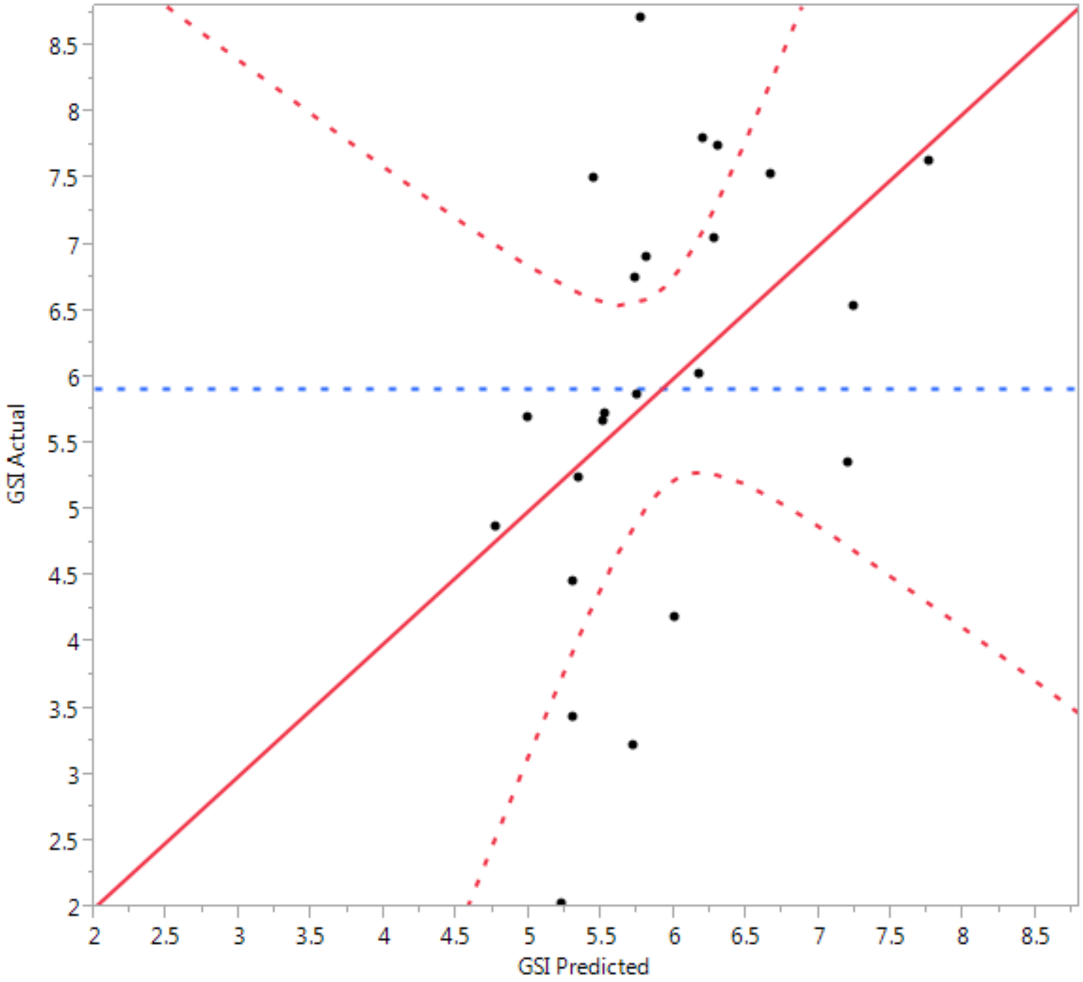

Figure 3. Plot of the actual female GSI values versus the predicted female GSI values. Red line = the plot of the predictive equation. Dashed blue line = mean residual of the observed female GSI value. Dashed red line = the upper and lower 95% confidence intervals.

Neither the upper nor lower 95% confidence intervals cross and deviate from the mean residual of the observed female GSI value indicating no statistical significance ($F = 0.84$, $P = 0.54$). Each of the explanatory variables was subsequently analyzed independently to assess their ability to predict mean female GSI values but all models displayed a lack of fit and R^2 values much lower (range $R^2 = 0.03–0.07$) than the total model indicating female GSI values were not related to measured water quality parameters.

Larval Fish

Targeted efforts to collect larval fish began in early July 2011 and continued for the remainder of the study period. These efforts were prompted by the incidental capture of larval specimens in minnow traps and seines during the June 2011 sampling effort. Larval fish were collected in all subsequent samples except the 17 October 2013 collection. The single larval specimen collected on 7 September 2011 was damaged to the point that ontogenetic stage could not be determined. While true larval fish (= proto, meso, or metalarval ontogenetic stage) were not collected in the October 2013 sample, several specimens that had recently achieved the juvenile stage were captured. These juvenile fish were small (13-16 mm SL) and relatively young. The continual collection of larval fish suggests reproduction was occurring throughout the year. There was not a clear correlation between female GSI values and larval fish occurrence in collections. While both 2011 and 2012 showed distinct peaks in female GSI values, this did not result in the subsequent collection of very young (i.e., protolarvae) fish. Few (n = 7) protolarvae were collected during the entire study period. Rather, later larval stages (post flexion mesolarvae and metalarvae) comprised the majority (77.1%) of larval fish specimens taken and they occurred in every collection that contained larval fish (n = 28) except one (16 Nov 2012; Figure 2).

Population Age Structure

Four age classes (0, 1, 2, and 3) were collected during the study period. In 2011, three age classes (0, 1, and 2) were collected in each of the samples except 27 April and 3 June. However, because larval fish were not targeted during those initial sampling efforts, it is unknown if age-0 fish were present in the system. The 22 June 2011 collection of larval Roundnose Minnow documented the presence of age-0 fish (Figure 4). Larval fish were subsequently collected in each of the 2011 collections meaning age-0 fish were being produced by the adult population during this time. Mean lengths of 2011 age-0 Roundnose Minnow ranged from 8.4 (±3.7) to 20.2 (±5.2) mm SL (Appendix I).

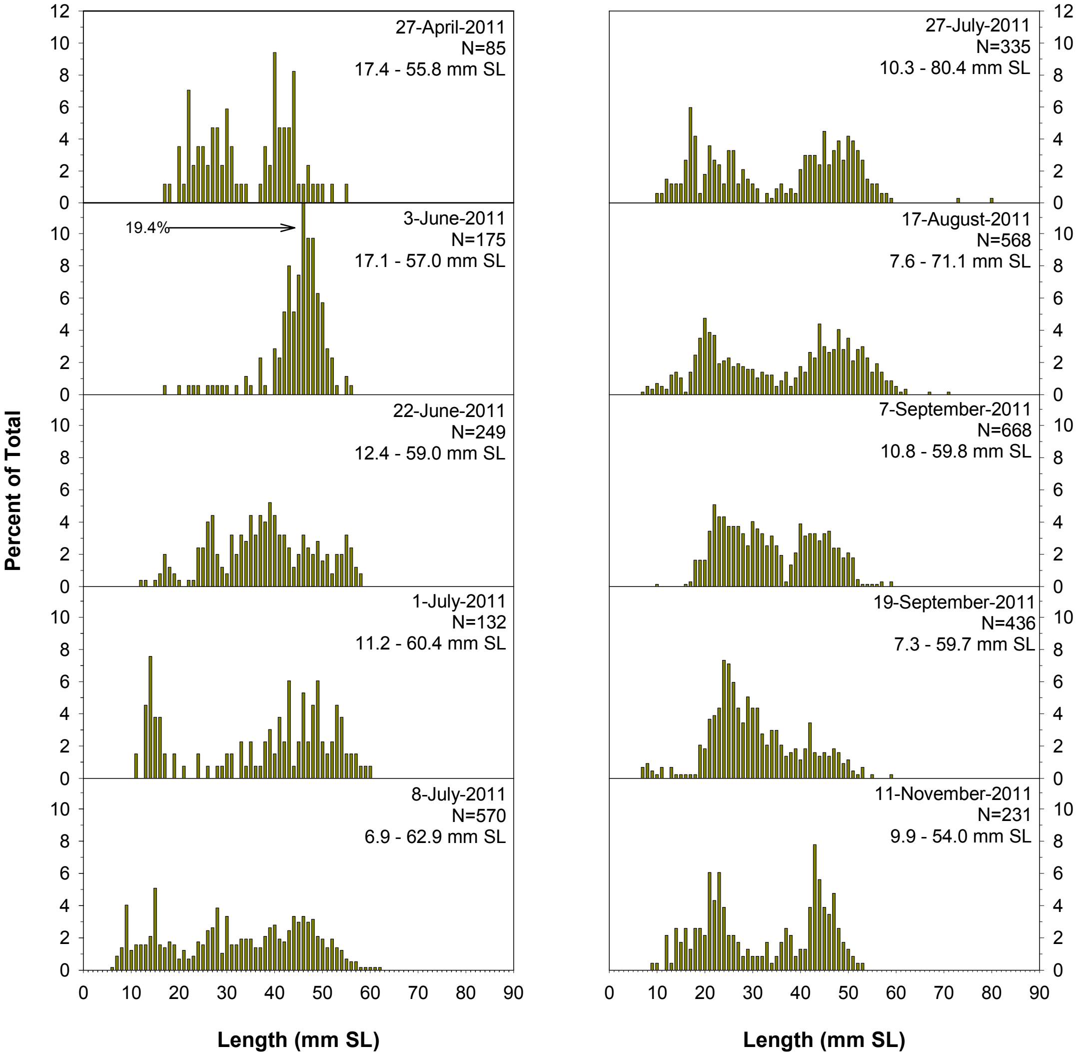

Figure 4. Length-frequency histograms of Roundnose Minnow collected in 2011. Larval fish collections began on 22-June-2011.

During 2012, larval Roundnose Minnows were present in all 12 samples; however distinguishing age classes of specimens in the 2012 collections was difficult. For example, given that all fish have the theoretical birthday of January 1, metalarval

Roundnose Minnow (<11.0 mm SL) collected on 6 January 2012 were age-1 fish. The six-day time period between 1 and 6 January is too short for an individual larva to progress from protolarva to metalarva, therefore those individuals were hatched sometime prior to 1 January (Figure 5). Metalarval Roundnose Minnows were again collected the following month, and it is unclear whether those fish were age-1 (i.e., hatched in late 2011), or age-0 fish hatched in early January 2012. By March 2012, age-0 Roundnose Minnow were in El Rito Creek. The 9 March samples contained some of the few protolarval Roundnose Minnow specimens collected during this study. Those specimens were likely only a few days old and were the result of 2012 spawning. Lengths of fish collected in March 2012 ranged from 7.6 – 82.8 mm SL with modal class regression analysis indicating four age classes (0, 1, 2 and 3) present [SI >2.0 among all age classes (Figure 5)].

The March 2012 collection is the only sample in which four age classes of Roundnose Minnow were detected in El Rito Creek. In all subsequent collections, early larval stages (i.e., protolarvae and mesolarvae) were documented in El Rito Creek as were age-1 and 2 fish (Figure 5). Mean length of 2012 age-0 Roundnose Minnow varied little ranging from 7.3 (±3.4) to 16.5 (±3.7) mm SL.

Age class structure of the 2013 Roundnose Minnow population was similar to that observed in 2012. Larval age-1 fish were again collected in January, and age of the smallest February fish was unclear. Young mesolarval Roundnose Minnow were collected in March 2013 confirming the presence of age-0 fish in the system (Figure 6). Between March and October of 2013, three age classes (0, 1 and 2) of Roundnose Minnow were documented in each collection. Mean length of 2013 age-0 Roundnose

Minnow ranged from 12.0 (±2.1) to 19.8 (±4.6) mm SL indicating reproduction from March through late September or early October.

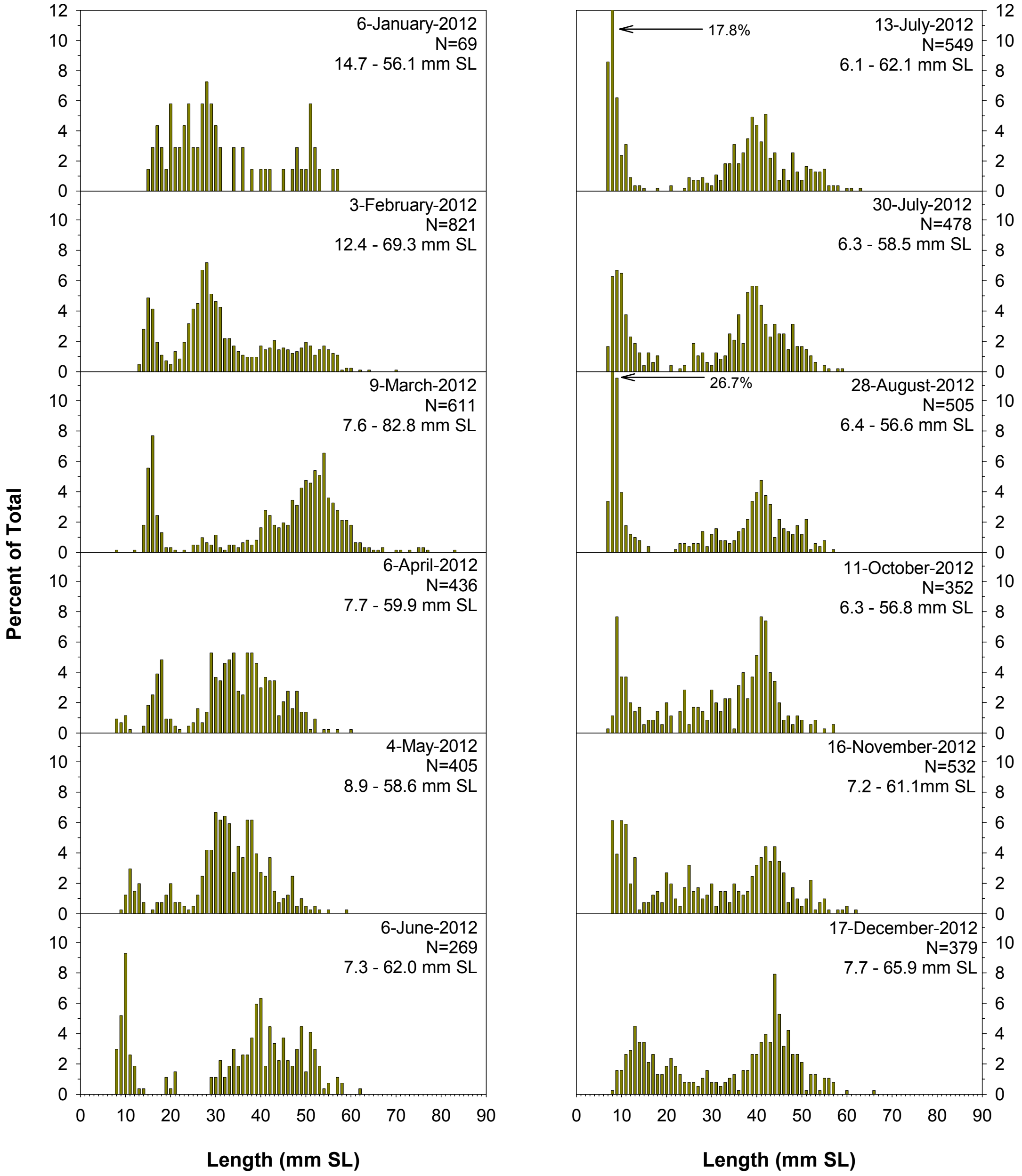

Figure 5. Length-frequency histograms of Roundnose Minnow collected in 2012.

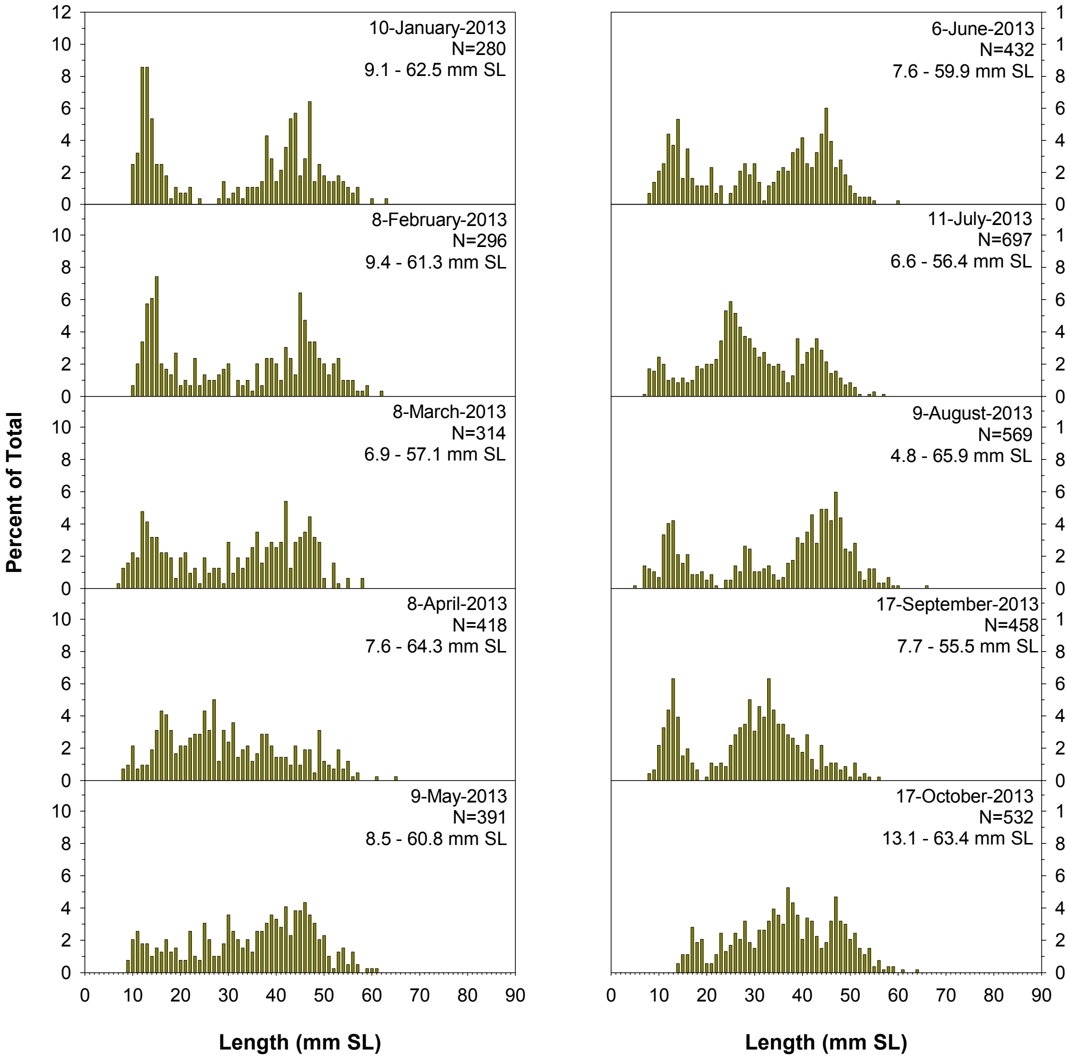

Figure 6. Length-frequency histograms of Roundnose Minnow collected in 2013.

Female-Male Sex Ratios

The sex of 1,752 Roundnose Minnow was determined for this study. During 2011, 2012, and 2013 sex was determined for 550, 702, and 500 fish, respectively. Sex ratios differed from the expected 1:1 ratio in all years and were biased towards a greater number of females (Table 1). Female Roundnose Minnow comprised 67.0% of the total sample and between 63.1% and 74.6% of the annual samples. Sex ratios (females) of individual samples ranged from 1% (3 June 2011) to 98% (17 August 2011).

Table 1. Sex ratios for Roundnose Minnow during 2011, 2012, 2013, and the entire study period with associated Chi-squared (X^2) and *P*-values. Expected ratios would be 1:1.

Year	**% of Females**	**% of Males**	**X^2 value**	***P* value**
2011	63.1	36.9	37.7	<0.0001
2012	64.5	35.5	59.3	<0.0001
2013	74.6	24.5	121.0	<0.0001
Study period	67.0	33.0	201.4	<0.0001

Female Length at Sexual Maturity

Examination of eviscerated female Roundnose Minnow revealed that a portion of females > 40 mm SL always contained mature eggs. Fish used to determine size at sexual maturity ranged from 24–39 mm SL (Table 2).

Table 2. Bin-lengths and female maturity status for each of the four seasonal Roundnose Minnow collections examined. All collections are from 2012 and each bin with a fish represents one specimen.

Month	**Bin 24–27 mm**	**Mature (Y/N)**	**Bin 28–31 mm**	**Mature (Y/N)**	**Bin 32–35 mm**	**Mature (Y/N)**	**Bin 36–39 mm**	**Mature (Y/N)**
Feb	N/A	-	29 mm	N	33 mm	N	37 mm	Y
Feb	N/A	-	29 mm	N	33 mm	N	37 mm	N
Feb	N/A	-	30 mm	N	34 mm	N	37 mm	Y
Feb	N/A	-	30 mm	N	35 mm	N	38 mm	Y
Feb	N/A	-	31 mm	N	35 mm	N	39 mm	Y
May	26 mm	N	29 mm	N	33 mm	N	36 mm	N
May	27 mm	N	29 mm	N	34 mm	Y	37 mm	Y
May	27 mm	N	30 mm	N	34 mm	N	38 mm	Y
May	27 mm	N	30 mm	N	34 mm	N	38 mm	Y
May	27 mm	N	31 mm	N	35 mm	N	39 mm	Y
Jul	N/A	-	28 mm	N	32 mm	N	37 mm	N
Jul	N/A	-	28 mm	N	34 mm	N	37 mm	N
Jul	N/A	-	28 mm	N	35 mm	N	38 mm	Y
Jul	N/A	-	29 mm	N	35 mm	N	39 mm	N
Jul	N/A	-	29 mm	N	35 mm	N	39 mm	N
Oct	N/A	-	28 mm	N	34 mm	N	37 mm	N
Oct	N/A	-	29 mm	N	34 mm	N	37 mm	N
Oct	N/A	-	29 mm	N	34 mm	N	37 mm	N
Oct	N/A	-	29 mm	N	35 mm	N	37 mm	Y
Oct	N/A	-	30 mm	N	35 mm	N	39 mm	Y

For each of the four seasonal collections examined, sexually mature females were present in the 36–39 mm SL bin. The smallest female with mature eggs was a 34 mm SL specimen collected May 2012 (Table 2, Figure 7).

Modal class regression analysis suggested all sexually mature female Roundnose Minnow were at least age-1. Mature females from the February 2012 collection were likely age-2. Mean length of age-1 Roundnose Minnow was 26.5 mm SL (±3.2 mm SL) and mean length for age-2 specimens was 43.3 mm SL (±10.5 mm SL). Given the time of year and substantial range in size of age-2 fish, mature female Roundnose Minnow in February 2012 would be age-2. Mean lengths for all age-1 fish during May, July, and October were 33.5 mm SL (±4.0 mm SL), 38.8 mm SL (±15.4 mm SL), and 34.6 mm SL (±6.2 mm SL) respectively. Mature female Roundnose Minnow collected during these months were age-1. In general, minimum size for mature female fish was 37–38 mm SL. The exception was a sexually mature 34 mm SL female Roundnose Minnow from the May 2012 collection. While important as it indicates the low-end range for sexual maturity, it was the only specimen (of 20) in the 32–35 mm size bin that was mature (Table 2, Figure 7).

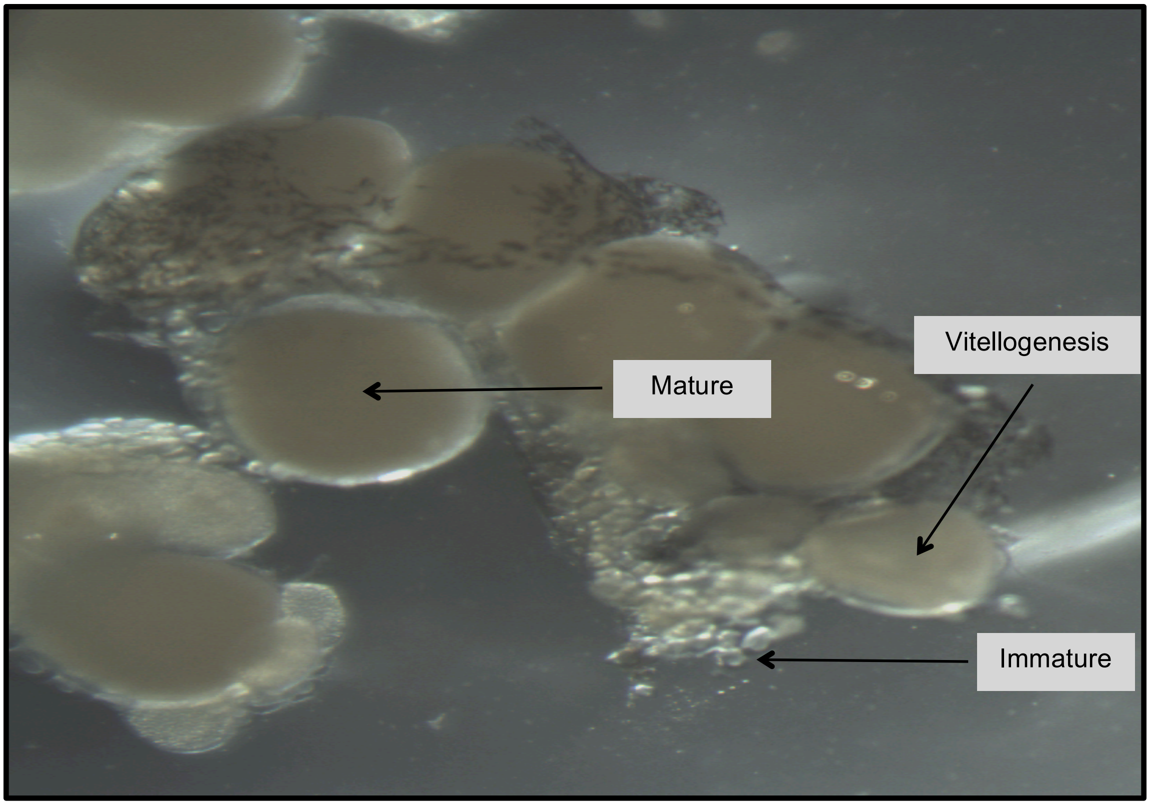

Figure 7. Three stages of egg maturation in female Roundnose Minnow. Photograph is of a portion of the gonad of the smallest (34 mm SL) sexually mature female examined.

Chapter 4

Discussion

The El Rito Creek population of Roundnose Minnow examined for this study revealed several unique characteristics, while also exhibiting traits typical of spring-associated species. The nearly continuous collection of larval specimens and likely year-round spawning by this fish is not unusual in the genus *Dionda*. In Pinto Creek and Devils River, (southwestern Texas) Devils River Minnow, *Dionda diaboli*, had a prolonged (winter, spring, summer) spawning season whereas Manantial Roundnose Minnow, *D. argentosa,* spawned year round (McMillan, 2011). The relatively stable thermal regimes in spring-associated systems are likely conducive to extended spawning periods (McMillan, 2011). Both Pinto Creek and Devils River are fed by artesian spring sources.

Artesian discharge from Blue Hole in Santa Rosa, NM is the primary water source for El Rito Creek and, as a result, annual water temperatures were relatively stable. Water temperatures during winter (mid-November 2012 to mid-February 2013) in the Pecos River, Santa Rosa, ranged from 3°C–18°C (data recorded with Onset Stowaway TidBit temperature loggers). During that same period, water temperature in El Rito Creek was 13°C–17°C. It is possible that elevated minimum winter water temperatures in El Rito Creek, not the narrow range of winter temperatures, promote year-round spawning in Roundnose Minnow (Baras, 1994, Pearse and Phillips, 1968, Zieba et al., 2010).

Annual female GSI values during the study period suggest, however, that spawning effort by the population of Roundnose Minnow was not uniform throughout the year. Both 2011 and 2012 showed statistically significant peaks in female GSI values.

While those peaks were not followed by the collection of large numbers of very young, protolarval specimens (which was predicted for samples during months with high female GSI values) the lack of protolarvae does not contradict the female GSI peaks. This earliest life stage may have been less susceptible to capture, or concentrated in habitats that were not routinely sampled. Any fish that survives to adulthood must pass through the protolarval stage, and this is one of the shortest (usually measured in days versus weeks) ontogenetic life stages for many fish species (Snyder and Muth, 2004). It is possible that the developmental rate of protolarval Roundnose Minnow was rapid and documentation the protolarval life stage was underrepresented due to the monthly sampling interval and difficulty in collecting that life stage. Although protolarval specimens were rare captures, the consistent collection of larval fish that were similar in age (i.e. post-flexion mesolarvae and metalarvae) is indicative of some level of continuous reproduction.

The lack of power by the total water quality model to explain female GSI values was unexpected. The original intent of monitoring water quality parameters was to incorporate a large variety of measures, including dissolved oxygen, pH, ammonia, and ammonium ions within the total water quality model. Despite costly refurbishing of the equipment immediately before initiation of the study, monthly calibration, downloading of the data, replacement of all batteries, and the deployment of a second back up unit, the HydroLab® Datasonde4a units used suffered multiple failures. For some of the parameters measured the failure was abrupt, resulting in an output that allowed me to identify precisely the moment of failure. These failures were overcome, in most cases, by replacing erroneous readings with data from the back-up unit (when available). If data from the back-up unit were not available, invalid data were removed and the remaining valid data paired with female GSI values for that time period.

Most HydroLab® Datasonde 4a failures occurred in the form of an incremental run up to a non-usable value. For example, the percent of dissolved oxygen within El Rito Creek was typically measured (on both the Datasonde4a and a hand held YSI water quality meter) between 40-60% with occasional readings either higher or lower. Readings of the Datasonde4a repeatedly showed an incremental increase (40%, 50%, 60%, 70%, 80%, 100%, 140%, 200% etc.) until the point of failure. Because of this, any cut off used to establish a “real” value and an “erroneous” value would have been speculative. Other reasons for failure included flood events, and the units spontaneously turning off despite ample battery power. Using these additional water quality parameters as explanatory variables may or may not have increased the power of the total model to predict female GSI values. That the existing water quality data do not provide insight into changes in female GSI values does not mean that accurate data would not have provided predictive power.

Several important conclusions resulted from this study. Viewed within the context of the triangular life history model (Winemiller 2005, Winemiller and Rose 1992), the population of Roundnose Minnow showed several characteristics of opportunistic strategists (Figure 8). These characteristics include smaller body size, short generation time and a presumed low investment per offspring. Population regulation of opportunistic species is typically not as sensitive to density-dependent factors, as they generally have populations below carrying capacity (Ross, 2013). However, the Roundnose Minnow does not fall directly on the end point of the triangular model. Little environmental variation within El Rito Creek and a longer life span compared to other *Dionda* species nudge this population towards the equilibrium end point of the model. Opportunistic- and equilibrium-classified populations are sensitive to environmental changes, although the magnitude and predictability of those changes usually differs (Winemiller 2005.)

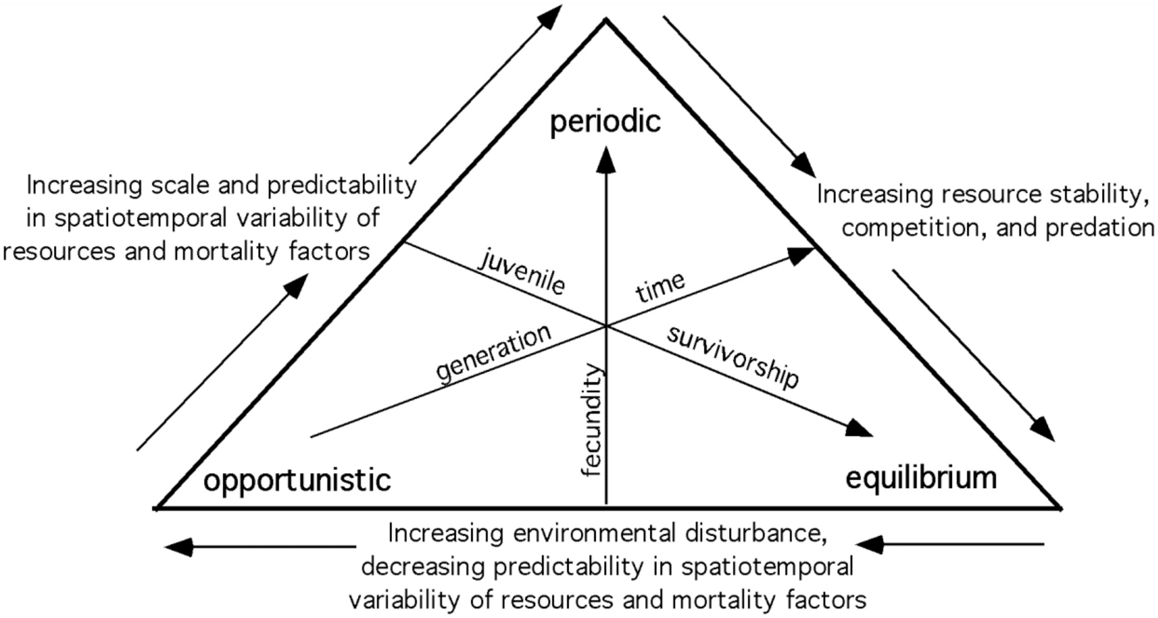

Figure 8. Triangular life history model showing environmental gradients selecting for endpoint life history strategies. (from Winemiller 2005).

Overall, the population of Roundnose Minnow in El Rito Creek should be capable of sustaining high turnover rates. Some portion of the population is engaged in reproductive activities during the entire calendar year, sex ratios are biased towards females, and those females are sexually mature at a smaller size than is reported for several other species of *Dionda*. These characteristics suggest a population that has a high intrinsic rate of increase. In the Devils River, the smallest documented mature female Devils River Minnow and Manantial Roundnose Minnow were 42 and 45 mm TL respectively (McMillan, 2011), while the smallest mature female Ozark Minnow, *D.*

nubila was 45 mm SL (Glazier and Taber, 1980). Additionally, none of the aforementioned *Dionda* species had more than three age classes at any point during the year whereas the Roundnose Minnow population in El Rito Creek showed four age classes.

Currently, the decommissioned power dam that impounds El Rito Creek is a barrier to any upstream fish movement and also isolates fish populations from the Pecos River. This type of habitat fragmentation is a known threat to the persistence of fish populations (Hoagstrom et al., 2011). Any reconstruction of this facility would further solidify this fragmentation, and disturb or remove habitat that Roundnose Minnow currently reside. Should the City of Santa Rosa proceed with the reconstruction of the power dam that now impounds El Rito Creek, establishment of a refugium population should be one of the first steps to safeguard this species prior to construction activities. A small number of adults collected for this study were transported alive to the City of Albuquerque's Bio-Park aquarium facilities. These fish survived in ambient temperature aquarium and some adults spawned in captivity without photoperiod, or hormonal manipulation.

Through collaborative efforts with local, and federal agencies, it may be possible to identify suitable, but currently unoccupied, habitats to establish additional populations of Roundnose Minnow. New populations could be established to further safeguard this species. Because the core of this Roundnose Minnow population is confined to a small geographic location that may someday be subject to considerable physical disturbances, relatively minor but prudent conservation efforts will be necessary to ensure its persistence.

Appendix I. Modal class progression analysis results.

Month	Day	Year	Age Class	Mean length of age class (mm SL)	S.D. (mm)
Apr	27	2011	1	26.5	3.1
Apr	27	2011	2	43.0	3.9
Jun	3	2011	1	22.8	9.1
Jun	3	2011	2	46.7	3.6
Jun	22	2011	0	17.6	1.5
Jun	22	2011	1	35.6	5.5
Jun	22	2011	2	51.4	4.4
Jul	1	2011	0	14.2	1.7
Jul	1	2011	1	35.8	5.1
Jul	1	2011	2	50.3	4.3
Jul	8	2011	0	14.1	3.3
Jul	8	2011	1	30.6	4.7
Jul	8	2011	2	47.0	4.4
Jul	27	2011	0	20.2	5.2
Jul	27	2011	1	43.2	4.0
Jul	27	2011	2	52.0	4.1
Aug	17	2011	0	10.5	NA, one fish
Aug	17	2011	1	27.0	3.9
Aug	17	2011	2	43.8	3.8
Sep	7	2011	0	11.5	2.4
Sep	7	2011	1	25.3	7.1
Sep	7	2011	2	48.7	4.8
Sep	19	2011	0	8.4	3.7
Sep	19	2011	1	27.2	3.3
Sep	19	2011	2	43.6	4.2
Nov	11	2011	0	15.4	1.2
Nov	11	2011	1	25.2	6.5
Nov	11	2011	2	45.8	2.8
Jan	6	2012	1	15.7	3.3
Jan	6	2012	2	27.2	3.0
Jan	6	2012	3	49.0	2.5
Feb	3	2012	0 and/or 1	17.0	2.8
Feb	3	2012	2	26.5	3.2
Feb	3	2012	3	52.3	10.3
Mar	9	2012	0	11.0	3.2
Mar	9	2012	1	23.9	4.0
Mar	9	2012	2	47.3	6.2
Mar	9	2012	3	70.9	3.6
Apr	6	2012	0	10.0	8.6
Apr	6	2012	1	33.6	5.7
Apr	6	2012	2	53.6	4.1
May	4	2012	0	16.5	3.7
May	4	2012	1	33.5	4.0
May	4	2012	2	44.1	4.9
Jun	6	2012	0	9.6	6.0
Jun	6	2012	1	34.1	8.1
Jun	6	2012	2	49.9	7.8
Jul	13	2012	0	7.3	3.6

Appendix I. continued.

Month	Day	Year	Age Class	Mean length of age class (mm SL)	S.D. (mm)
Jul	13	2012	1	37.0	5.9
Jul	13	2012	2	55.8	5.1
Jul	30	2012	0	9.3	2.1
Jul	30	2012	1	38.8	15.4
Jul	30	2012	2	53.7	3.5
Aug	28	2012	0	8.2	3.2
Aug	28	2012	1	28.6	4.1
Aug	28	2012	2	42.1	3.5
Oct	11	2012	0	12.5	3.0
Oct	11	2012	1	34.6	6.2
Oct	11	2012	2	49.7	2.8
Nov	16	2012	0	8.4	1.7
Nov	16	2012	1	23.5	3.8
Nov	16	2012	2	46.1	9.9
Dec	17	2012	0	13.0	2.5
Dec	17	2012	1	24.7	5.5
Dec	17	2012	2	46.4	14.5
Jan	10	2013	1	12.0	2.1
Jan	10	2013	2	25.6	8.7
Jan	10	2013	3	49.3	10.2
Feb	8	2013	0 and/or 1	12.5	1.6
Feb	8	2013	2	23.2	8.1
Feb	8	2013	3	50.0	6.6
Mar	8	2013	0	12.5	2.8
Mar	8	2013	1	32.1	4.5
Mar	8	2013	2	42.7	3.5
Apr	8	2013	0	14.1	4.6
Apr	8	2013	1	27.5	4.5
Apr	8	2013	2	43.1	5.6
May	9	2013	0	13.5	3.8
May	9	2013	1	28.9	4.0
May	9	2013	2	42.9	9.8
Jun	6	2013	0	11.1	2.1
Jun	6	2013	1	23.9	3.4
Jun	6	2013	2	40.5	5.0
Jul	11	2013	0	11.6	2.3
Jul	11	2013	1	24.9	4.3
Jul	11	2013	2	42.1	3.5
Aug	9	2013	0	14.0	2.9
Aug	9	2013	1	29.0	3.1
Aug	9	2013	2	45.7	4.8
Sep	17	2013	0	12.3	2.5
Sep	17	2013	1	29.9	3.8
Sep	17	2013	2	42.7	6.6
Oct	17	2013	0	19.8	4.6
Oct	17	2013	1	33.6	4.5
Oct	17	2013	2	48.0	3.3

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