Habitat Associations, Life History and Diet of the Sabine Shiner Notropis sabinae in an East Texas Drainage

CASEY S. WILLIAMS[1] AND TIMOTHY H. BONNER

Department of Biology/Aquatic Station, Texas State University-San Marcos, San Marcos 78666

ABSTRACT.—We examined aspects of the ecology of *Notropis sabinae*, the Sabine shiner, including habitat associations, population age structure, reproduction and diet in two east Texas streams from November 2001 through October 2002. *Notropis sabinae* exhibited no strong seasonal habitat associations, but generally were found in relatively shallow slow flowing runs and riffles. The population consisted of three age groups (ages 0, 1, 2) with age-1 fish being the most abundant. Estimated maximum life span was 2.5 y. Reproductively mature individuals were observed from May through October. Temporal patterns in ovarian development, gonadosomatic index and ova development indicated that *N. sabinae* spawns multiple clutches of eggs over an extended spawning period. Stomach contents consisted primarily of aquatic insects, followed by other aquatic taxa (*e.g.,* Collembola, Crustacea and Hydracarina) and terrestrial insects.

INTRODUCTION

Notropis sabinae, the Sabine shiner, inhabits lotic environments ranging from small headwater streams to large rivers. Populations can be found from the San Jacinto drainage of eastern Texas and eastward through central Louisiana to the Big Black and Yazoo drainage systems of Mississippi (Douglas, 1974; Hubbs *et al.*, 1991; Ross, 2001). In addition, northern populations disjunct from the gulf coast drainages exist in three river systems (White, Black and St. Francis rivers) in northern Arkansas and southern Missouri (Gilbert, 1978; Robison and Buchanan, 1988). Although Warren *et al.* (2000) consider this species to be currently stable, *N. sabinae* was designated as a species of conservation concern in Texas and Louisiana by the U.S. Forest Service Region 8 and U.S. Fish and Wildlife Service Region 2, and as a species of special concern in Mississippi (Ross, 2001).

Information on the ecology of *Notropis sabinae* is limited to only a few investigations. These studies indicate that *N. sabinae* is a benthic species that uses habitat with sandy substrate and moderate current velocities with abundances ranging from rare to common (Gilbert, 1978; Moriarty and Winemiller, 1997; Ross, 2001). In Sabine River tributaries of Texas and Louisiana, reproduction takes place from April through September with multiple egg clutches spawned by 1 to possibly 3 y old females; maximum standard length is 49 mm (Heins, 1981). Little additional information is available about temporal trends in habitat associations and population age structure of *N. sabinae* within the streams it inhabits. Herein, we provide information concerning aspects of the life history of *N. sabinae* from a stream system (Banita Creek and LaNana Bayou, Nacogdoches County, Texas) that historically (Dickens, 1950) and presently supports a large population of this species. Specifically, we sought to assess habitat associations, number of age groups present, longitudinal distribution, gonadal maturation, sex ratio and food habits of the *N. sabinae* population in this stream system.

[1] Corresponding author: Telephone: (512) 245-3547; FAX: (512) 245-7919; e-mail: cw1057@txstate.edu

<div style="text-align:center">METHODS</div>

Banita Creek and LaNana Bayou (Nacogdoches County) are tributaries of the Angelina River in east-central Texas. Both streams originate north of Nacogdoches, Texas and flow south until merging near the southern extent of the city. Both are perennial, shallow streams with silt, sand and bedrock substrates. Channel geomorphic units (Goldstein and Meador, 2004) range from swift flowing bedrock chutes and riffles to slow flowing runs and pools. In some reaches, concrete and other debris associated with municipal streams (*e.g.,* discarded tires and furniture) are common. Riparian areas and watersheds are used primarily for urban or agricultural purposes.

Sampling methodology.—We collected quantitative and qualitative habitat information and fish monthly from November 2001 through October 2002 at three sites on Banita Creek and one site on LaNana Bayou. Collection sites were established at upstream (Site 1) and middle (sites 2 and 3) reaches of Banita Creek and downstream (Site 4) on LaNana Bayou. Sites 1, 2 and 3 were spaced along 10.5 km of Banita Creek and were separated by 2.5 and 8.0 km, respectively. Site 4 was located downstream from the Banita Creek and LaNana Bayou confluence and 2.9 km from Site 3. Site lengths were not predetermined and varied monthly depending on the availability and length of geomorphic units. At each site, we collected *Notropis sabinae* from available geomorphic units (*e.g.,* riffles, runs, pools, backwaters and chutes as defined by Armantrout, 1998) with a Smith-Root Model 12-B POW backpack electrofisher and seines (1.2 by 1.8 m, mesh size: 3.2 mm; 1.8 by 2.4 m, mesh size: 3.2 mm). We placed block nets (mesh size: 4 mm) across the entire width of the stream at upstream and downstream boundaries of each geomorphic unit to prevent fish escapement. Within each geomorphic unit, we electrofished areas surrounding structures (undercut banks, woody debris, boulders, etc.) that hindered seining efforts and conducted a minimum of two seine hauls over the entire area. However, we continued seining until the number of individuals collected in each seine haul was greatly reduced and no new species were collected. Fish collected by electrofishing and seining were combined and temporarily held in buckets filled with creek water. Individuals were then identified to species, enumerated and released except for the first 30 *N. sabinae* caught from the bucket per site. We exposed the first ten individuals to a lethal dose of MS-222 (80 mg/liter) and preserved them in 10% buffered formalin for gonad and stomach content analysis; we then measured total length (TL; mm) of the next 20 *N. sabinae* and released them. In addition to fish collections, we measured the following physical parameters for each geomorphic unit: length, width, mean current velocity, mean and maximum depth and percent woody cover, vegetation, detritus and substrate type. We measured current velocity (Marsh-McBirney Flowmate Model, 2000) and depth at 0.5 m increments across one representative transect per geomorphic unit, using these measurements to calculate mean current velocity and mean depth for each unit. We visually estimated substrate type (sand, silt, bedrock, gravel, cobble), woody cover, vegetation and detritus as the percentage of area occupied within each geomorphic unit (Taylor and Lienesch, 1996; Taylor and Warren, 2001).

In the laboratory, we weighed each preserved *Notropis sabinae*, removed and weighed gonads and removed the digestive tract from the esophagus to the first loop of the intestine. With the aid of a dissecting microscope, we determined the sex of each individual and the stage of ovarian development (*i.e.,* immature or resting, developing, mature, spent; Phillip, 1993) for each female. Previously reported ovarian descriptions (Heins and Rabito, 1986; Heins and Baker, 1989, 1993) include up to five stages (*e.g.,* latent, early maturing, late maturing, mature, ripening and ripe). However, we felt descriptions used by Phillip (1993) were more appropriate for this study because the level of resolution was

adequate to determine seasonal reproductive trends and because ovarian stages were more easily and consistently recognized by macroscopic examination, especially during later stages of ovarian maturation. Ovarian stages described by Phillip (1993) are similar to these other studies: immature or resting stage is equivalent to latent; developing stage is equivalent to early and late maturing stages; mature stage is equivalent to mature, ripening and ripe categories. Phillip (1993) describes an additional stage (*i.e.,* spent) that includes fishes that have recently spawned; ovary is flaccid and lacks newly developing oocytes. Weight of gonads was used to calculate a gonadosomatic index [GSI; (gonad weight/fish weight)*100] for each fish. Male and female GSIs were pooled across sites to calculate mean monthly GSIs. Oocyte diameters were measured monthly from the ovaries of three mature females collected between May and October 2002. For each fish, ovaries were separated and the left ovary was placed in a clear plastic dish. Oocytes were separated by stirring and gently teasing apart with small forceps. Once separated, oocytes were redistributed in the dish by swirling and gently shaking the dish. The dish was placed under a dissecting microscope with an ocular micrometer and viewed at 25× magnification. Oocytes (n > 25) were measured to the nearest 0.05 mm at their longest axis as encountered along a horizontal transect.

We pooled *Notropis sabinae* lengths across sites for each month, grouped them into 2 mm length increments and constructed length frequency histograms. Age groups and modal lengths of each age group were estimated with length frequency distribution analysis (LFDA, Version 5; Kirkwood *et al.*, 2001). Electronic length frequency analysis method (ELENFAN) was used to estimate the following model parameters for the von Bertalanffy non-seasonal and seasonal growth equations: growth rate (K), asymptotic length (L_∞), time at which fish length is zero (t_0) and phase (t_s) and amplitude (C) of seasonal growth oscillations. Parameters K and L_∞ initially were estimated during parameter maximization using the von Bertalanffy non-seasonal growth equation. Remaining model parameters and refinement of K and L_∞ were estimated during parameter maximization using seasonal growth equation. We made two assumptions of the *N. sabinae* population: age 2 is the maximum age of *N. sabinae* (Heins, 1981) and fish growth is greater from April through September than October through March. These assumptions allowed for selection of model parameters that generated predicted growth curves parsimonious with the length frequency histogram, independent of goodness-of-fit scores. Maximization of model parameters ceased after growth curves fitted reasonably with our data. Age groups were labeled according to their age on 1 January 2002; fish that were spawned in 2000 were labeled age 2 and fish that were spawned in 2001 were labeled age 1. Fish spawned during the study period (January–October 2002) were referred to as age 0. Across age groups, we calculated catch per unit effort (CPUE) for each site and month in order to examine patterns in longitudinal distribution. Catch per unit effort was calculated as the number of *N. sabinae* collected per area sampled (m^2).

We weighed and separated contents of the removed portion of the digestive tract into broad taxonomic groups (*i.e.,* aquatic insects, terrestrial insects, unidentifiable insects, aquatic non-insects, intestinal parasites), detritus, plant material or inorganic material. Aquatic insect taxonomic groups were further segregated into the lowest practical taxon. We measured wet weight of each taxonomic group to the nearest mg. A weight of 0.1 mg was assigned when a taxonomic group was <0.1 mg. Unidentifiable insects were defined as parts or highly masticated individuals that precluded confident identification. Detritus was defined as material that remained after taxonomic groups, inorganic material (*e.g.,* sand and silt) and plant material were removed. We averaged percent weight of each food group among fish by month and compared across months.

Statistical methods.—Temporal patterns in Banita Creek and LaNana Bayou habitat characteristics were assessed with principle components analysis (PCA). Qualitative data (*i.e.,* geomorphic units) were represented by dummy variables. Quantitative data (*i.e.,* physical parameters) were z-score-transformed (Krebs, 1999). Generated PCA axes scores were grouped into four time intervals that generally reflect seasonality: November 2001 through January 2002 (Winter); February through April 2002 (Spring); May through July 2002 (Summer); August through October 2002 (Fall). Occurrence, abundance and density associations with PCA scores were assessed by season with Pearson product-moment correlation (Zar, 1999). Significance level was adjusted using a Bonferroni procedure ($\alpha = 0.05/c$, where c equals number of seasons) to accommodate multiple comparisons (Quinn and Keough, 2002).

Univariate analysis was used to assess similarities between male and female GSIs, sex ratios and to further examine patterns in *Notropis sabinae* seasonal distributions among available geomorphic units and current velocity and depth gradients. Concordance between male and female monthly mean GSIs was assessed using Pearson product-moment correlation ($\alpha = 0.05$). Chi-square goodness of fit tests were used to test for departure in a 1:1 sex ratio ($\alpha = 0.05$) and to compare expected and observed *N. sabinae* abundance among geomorphic units ($\alpha = 0.05/4$). Kolmogorov-Smirnov (KS) tests were used for ordinal data to test differences between expected and observed *N. sabinae* abundance among current velocity (0.05 m/s intervals) and depth (0.05 m intervals) gradients ($\alpha = 0.05/4$). Expected values for goodness of fit and KS tests were defined as the number of *N. sabinae* expected in each geomorphic unit, current velocity interval or depth interval if distribution was random. We determined expected values by pooling abundance and habitat data across sites and months within each season, calculating the areal (m^2) proportion for each geomorphic unit type, current velocity or depth interval and multiplying by the total number of *N. sabinae* collected.

RESULTS

HABITAT ASSOCIATIONS

Banita Creek and LaNana Bayou were relatively narrow, clean swept run and riffle dominated streams with predominately sand, gravel and bedrock substrates. Collectively, pools, backwaters and chutes comprised less than 5% of sampled areas (Table 1). Among sites, mean stream width ($\pm$SE) ranged from 3.0 (±0.24) to 6.8 (±0.85) m; mean depth ranged from 0.19 (±0.02) to 0.29 (±0.04) m; and mean current velocity ranged from 0.13 (±0.04) to 0.30 (±0.06) m/s. Stream width and current velocity increased from upstream to downstream; however, mean depth was greatest at Site 3. Detritus, woody debris and aquatic vegetation generally were less than 10% across sites although percent detritus was greater (46%) at Site 1 before a spate scoured the site in December 2001. Gravel, cobble and bedrock were most abundant at sites 1 and 2 whereas sand, gravel and bedrock were more abundant at sites 3 and 4.

The first three PCA axes explained 45% of total variation in qualitative and quantitative habitat data (Table 2). The first PCA axis (19.2% of total variation) described a current velocity and water depth gradient (Fig. 1). Habitats with highest negative loadings on PCA axis 1 were riffles and chutes with relatively swift current velocities, shallow depths, and bedrock and cobble substrate. Habitats with highest positive loadings were runs with relatively slower current velocities, greater depths and stream widths and silt substrate. The second PCA axis (13.3%) described primarily a substrate gradient. Habitats with highest negative loadings on PCA axis 2 were those with greater amounts of bedrock substrate,

TABLE 1.—Stream order, percent habitat and substrate and mean (±SE) monthly habitat parameters for three sites on Banita Creek (sites 1–3) and one site on LaNana Bayou (Site 4), Texas, collected from November 2001–October 2002

	Site 1	Site 2	Site 3	Site 4	Total
Stream Order	1	2	2	3	
Mesohabitat (%)					
Run	69.6	75.0	90.3	84.5	77.7
Riffle	25.8	25.0	9.0	10.5	18.3
Pool	4.6	—	—	2.5	3.0
Backwater	—	—	—	2.5	0.8
Chute	—	—	0.7	—	0.2
Substrate (%)					
Sand	1.5	6.2	33.6	21.5	17.7
Silt	13.0	7.1	19.1	16.0	13.6
Gravel	17.6	30.8	4.8	51.8	27.9
Cobble	3.7	29.5	3.2	10.7	9.7
Bedrock	64.2	26.3	39.3	—	31.1
Mean detritus (%)	8.0 (±4.6)	1.8 (±1.3)	0.7 (±0.5)	0.7 (±0.3)	1.3
Mean woody debris (%)	5.3 (±2.3)	6.4 (±1.9)	4.1 (±0.1.05)	7.8 (±2.2)	7.0
Mean vegetation (%)	—	—	0.8 (±0.82)	—	0.2
Mean length (m)	171.5 (±12.26)	92.2 (±3.7)	112.5 (±6.4)	116.8 (±12.1)	—
Mean width (m)	3.0 (±0.24)	3.4 (±0.37)	5.6 (±0.39)	6.8 (±0.85)	4.3
Mean depth (m)	0.19 (±0.02)	0.19 (±0.01)	0.29 (±0.04)	0.28 (±0.03)	0.26
Mean current velocity (m/s)	0.13 (±0.04)	0.19 (±0.06)	0.22 (±0.08)	0.30 (±0.06)	0.22

chutes, greatest maximum depth and vegetation. Habitats with highest positive loadings were those with greater amounts of gravel and cobble substrates, greater percent detritus and silt substrate. The third PCA axis (12.7%) contrasted slack water habitats from flowing water habitats. Habitats with highest negative loadings on PCA axis 3 were those with measurable current velocities common to areas with greater stream width and gravel substrate. Habitats with highest positive loadings were backwater areas with large amounts of detritus and silt substrates.

A total of 1246 *Notropis sabinae* were collected from 49% of geomorphic units sampled ($n=$ 149) from November 2001 through October 2002 (Table 3). Among seasons, *N. sabinae* occurrence, abundance and density were not correlated with PCA axes 1–3 except during the fall (August through October 2002) when occurrence (25 of 47 geomorphic units sampled) and abundance (n = 581) were positively associated (r = 0.38; P = 0.009; r = 0.43; P = 0.002, respectively) with PCA axis 1 (*i.e.,* habitats with greater depths, runs and width) (Fig. 1).

Although *Notropis sabinae* occurrence, abundance and density were not often associated with habitat characteristics among multivariate gradients, their abundance was not random among geomorphic units, current velocity intervals and depth intervals when tested with univariate analyses. Runs were the most abundant geomorphic units available (Table 1) and contained the greatest number of *N. sabinae*; however, their abundance was less than expected in runs and more than expected in riffles from winter through summer (P < 0.01; Table 4). Pools were the third most abundant geomorphic unit available and contained no *N. sabinae*. Chutes were the least abundant geomorphic unit, but observed abundances of *N. sabinae* were greater than expected when chutes were available. Among current velocity

TABLE 2.—Loadings and percent variance (%) explained by qualitative and quantitative habitat parameters on principle components axes (PCA) 1–3 for three sites on Banita Creek (Sites 1–3) and one site on LaNana Bayou (Site 4), Texas, from November 2001–October 2002

	PCA		
Parameter	1	2	3
Backwater	0.227	0.062	**0.331**
Pool	0.207	−0.071	−0.028
Run	**0.513**	−0.089	−0.025
Riffle	**−0.594**	0.189	−0.088
Chute	−0.290	**−0.240**	−0.003
Current velocity (cm/s)	**−0.382**	−0.018	**−0.547**
Depth (cm)	**0.737**	−0.122	−0.123
Maximum depth	**0.782**	**−0.351**	−0.223
Stream width (m)	**0.512**	−0.021	**−0.458**
Silt substrate (%)	**0.404**	**0.217**	**0.589**
Sand substrate (%)	0.395	−0.125	−0.035
Gravel substrate (%)	0.136	**0.680**	**−0.310**
Cobble substrate (%)	−0.223	**0.445**	−0.293
Bedrock substrate (%)	**−0.438**	**−0.822**	0.098
Woody debris (%)	0.289	0.085	0.039
Vegetation (%)	0.165	**−0.225**	0.013
Detritus (%)	0.090	**0.260**	**0.687**
% Variance explained	19.2	13.3	12.7

intervals, *N. sabinae* were more abundant (80%) in relatively slower current velocities (0–0.2 m/s; 54% of total area) and less abundant (20%) in swifter currents (0.25–0.95 m/s; 46% of total area) (Fig. 2a). Seasonally, *N. sabinae* abundance among current velocity intervals differed from expected during winter ($D = 0.45$, P < 0.01) and summer ($D = 0.14$, P < 0.01) only; *N. sabinae* were more abundant than expected (>30%) in current velocities ranging from 0.1–0.20 m/s (<25% of total area). Among depth intervals, *N. sabinae* were more abundant (67%) in shallow waters (≤0.25 m; 51% of total area) and less abundant (33%) at depths ranging from 0.3 to 1.2 m (49% of total area; Fig. 2b). Seasonally, *N. sabinae* abundance among depth intervals differed from expected during the winter ($D = 0.55$, P < 0.01) and summer ($D = 0.24$, P < 0.01) only. During these times, percent of mean depths >0.3 m increased to >60% however, ≥60% of *N. sabinae* were collected from areas with mean depths <0.25 m.

POPULATION STRUCTURE AND LONGITUDINAL DISTRIBUTION

Seasonal growth curves with parameters $K = 0.84$, $L_\infty = 68.0$, $t_0 = -0.03$, $t_s = 0.5$ and $C = 0.9$ provided a reasonable fit to the length frequency histograms (Fig. 3). However, these parameters underestimated growth of age-0 fish. Nevertheless, the ELENFAN method classified three age groups in the population. Age-2 fish reached a maximum total length of 61 mm and were collected during November 2001 (3%), February 2002 (4%) and May 2002 (2%). Age-1 fish were collected from November 2001 through October 2002, ranged in size from 20 mm (January 2002)–57 mm (July 2002), and were the most abundant age group from November 2001 through June 2002 (61–100%). Age 1 abundances decreased steadily through the summer, comprising only a small proportion of the population by September and October 2002 (<5%). Age-0 fish were first collected in June 2002, the most abundant
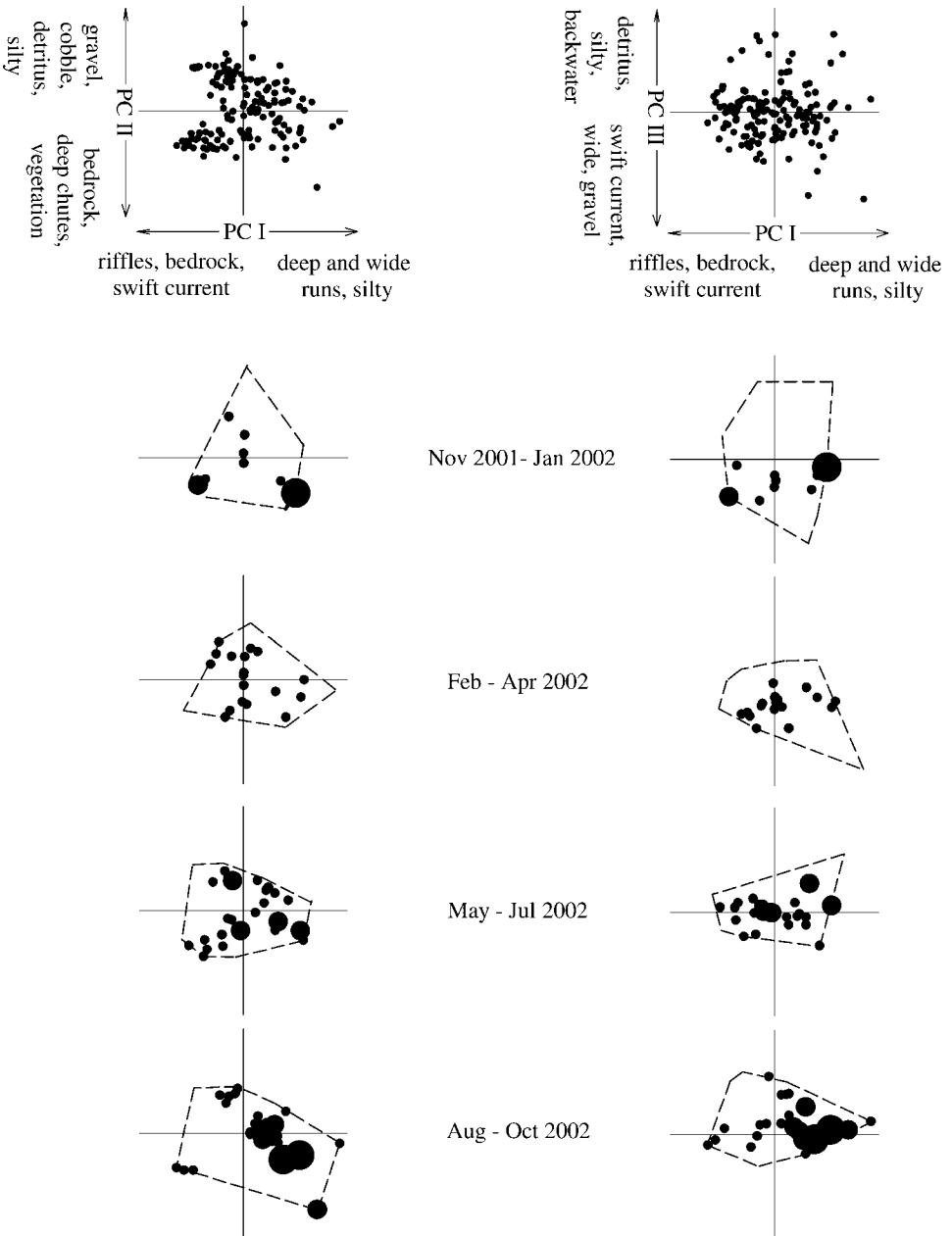
FIG. 1.—Plots of all geomorphic units on principal component axis I, II and III. Subsequent plots illustrate *Notropis sabinae* occurrence (circle) and abundance (circle size: small <25 individuals; medium = 25–75; and large > 75) by season. Dashed line envelops geomorphic units with or without *N. sabinae* by season

TABLE 3.—Seasonal correlations among *Notropis sabinae* occurrence, abundance and density and principle component axes 1–3 for three sites on Banita Creek and one site on LaNana Bayou, Texas, collected from November 2001–October 2002. Asterisk denotes significant correlation with a Bonferroni adjusted α (0.05/4 for seasonal comparisons)

Date		PC axis 1		PC axis 2		PC axis 3	
		r	P	r	P	r	P
Occurrence	% of geomorphic units with *N. sabinae*						
Nov. 2001–Jan. 2002	29	0.03	0.86	−0.26	0.15	−0.36	0.05
Feb.–Apr.	48	0.08	0.66	0.25	0.19	−0.16	0.42
May–Jul.	60	0.09	0.56	−0.08	0.62	−0.09	0.55
Aug.–Oct.	53	0.38	0.009*	−0.02	0.87	−0.13	0.37
Abundance	n						
Nov. 2001–Jan. 2002	202	0.14	0.45	−0.29	0.11	−0.14	0.44
Feb.–Apr.	113	0.04	0.83	0.19	0.32	−0.11	0.56
May–Jul.	350	0.20	0.19	−0.20	0.20	0.14	0.37
Aug.–Oct.	581	0.43	0.002*	−0.23	0.12	−0.14	0.34
Density	mean CPUE						
Nov. 2001–Jan. 2002	0.58	−0.03	0.85	−0.32	0.08	−0.18	0.32
Feb.–Apr.	0.39	−0.24	0.22	0.40	0.03	−0.15	0.44
May–Jul.	1.21	−0.26	0.10	−0.24	0.12	0.06	0.70
Aug.–Oct.	1.47	0.15	0.31	0.03	0.85	0.08	0.60

age group from July through October (60–96%) and reached a maximum length of 52 mm TL by October 2002.

Heterogeneity in *Notropis sabinae* occurrence and density was observed among sites and months (Table 5). At Site 1, *N. sabinae* was not detected until April 2002. Thereafter, fish were collected through October and generally consisted of age-1 fish. Among all sites, densities were greatest at sites 2 and 3 from November 2001 through September 2002. At Site 4, *N. sabinae* was not detected until February 2002. However, by October 2002, highest CPUE during this study (0.26/m²) was found at Site 4. Age-0 fish were first collected from sites 3 and 4 during June and July 2002. Age-0 fish abundance and CPUE in general increased at all sites from August through October 2002.

GONADAL DEVELOPMENT AND GSI

Female *Notropis sabinae* gonadal development occurred from April through October 2002. Female gonadal quiescence extended from November 2001 through March 2002 with all individuals (n = 47; TL = 25–55 mm) identified as immature or resting. Gonadal recrudescence occurred in April 2002 with 62% of the females (n = 13; TL = 34–54 mm) containing developing ovaries. In May 2002, 17% of females (n = 30; TL = 34–44 mm) contained resting or immature ovaries, 10% contained developing ovaries and 73% contained mature ovaries. All females (n = 21; TL = 40–54 mm) contained mature ovaries in June and July 2002. In August, 93% of females (n = 15; TL = 39–53 mm) contained mature ovaries and 7% contained developing ovaries. In September, 9% of females (n = 11; TL = 39–50 mm) contained immature or resting ovaries, 9% contained developing and 82% contained mature ovaries. In October, 46% of females (n = 24; TL = 37–54 mm) contained immature or resting ovaries, 8% contained mature and 46% contained spent ovaries. The smallest female with developing ovaries was 38 mm TL and collected in May 2002.

TABLE 4.—Seasonal expected and observed numbers of *Notropis sabinae* among available geomorphic units collected from three sites on Banita Creek (Sites 1–3) and one site on LaNana Bayou (Site 4), Texas, from November 2001 through October 2002

	Winter	Spring	Summer	Fall
Run				
Exp.	156.6	61.9	296.6	548.1
Obs.	128	58	275	558
Riffle				
Exp.	42.8	42.4	39.5	25.5
Obs.	74	55	47	3
Pool				
Exp.	2.0	8.7	4.3	1.7
Obs.	0	0	0	0
Backwater				
Exp.	1.0	—	8.0	2.6
Obs.	0	—	0	10
Chute				
Exp.	—	—	1.6	3.1
Obs.	—	—	10	10
X^2	30.7	12.7	15.2	42.78
df	3	2	4	4
P	<0.01	<0.01	<0.01	<0.01

Mean monthly GSI for females corresponded with temporal patterns in ovarian development and was postively correlated with male GSI values (r = 0.97; P < 0.01). Mean monthly female GSI was <2% (n = 47; TL range: 25–55 mm) during gonadal quiescence, elevated (>5%; n = 76; TL range: 34–54) from May through September and decreased to <2% (n = 25; TL range: 34–54) in October (Fig. 4). Mean male GSI was <0.2% (n = 48; TL range: 25–55) from November to March, elevated (>0.6%; n = 90; TL range: 35–59) from May through September and decreased to 0.2% (n = 13; TL range: 37–52) in October. Sex ratio did not differ from 1:1 ($X^2_1 = 0.07$, P = 0.79).

Individual female *Notropis sabinae* produced multiple cohorts of distinct oocyte sizes throughout the spawning period. Trimodal distributions of oocyte diameters represented three oocyte size classes from May through October 2002 (Fig. 5). During this period, size groups consisted of small previtellogenic oocytes and two cohorts (*i.e.,* medium and large) of vitellogenic oocytes.

FOOD HABITS

Among 309 *Notropis sabinae* examined (TL range: 18–62 mm), digestive tract contents by weight consisted of aquatic insects (40%, unweighted average across months), detritus

$\longrightarrow$

FIG. 2.—Percent occurrence of *Notropis sabinae* along current velocity (a) and depth (b) intervals collected from three sites on Banita Creek and one site on LaNana Bayou, Nacogdoches, Texas, from November 2001 through October 2002

a)

b)
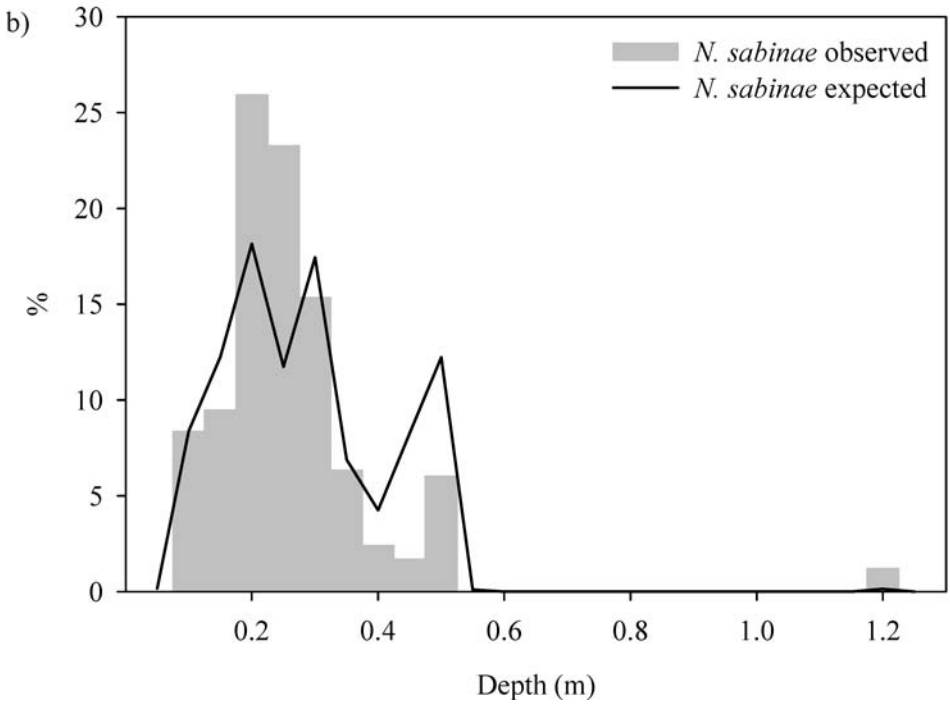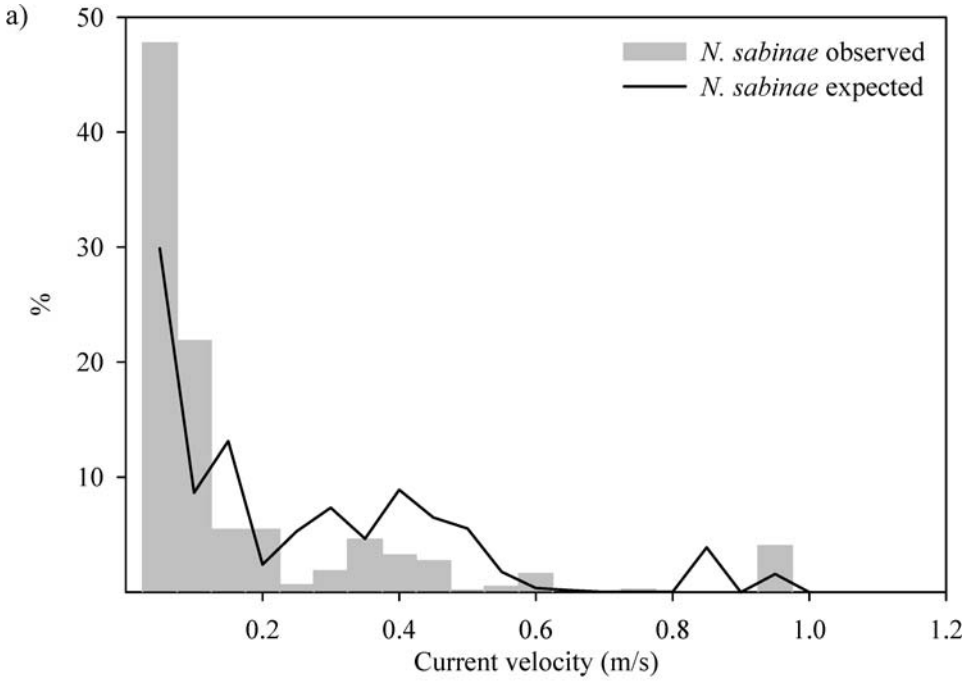
(27%), cestodes (19%), sand or silt particles (9%), unidentified aquatic insects (2.7%), terrestrial insects (1.8%), crustaceans (0.3%), plant material (0.1%) and Collembola and Hydracarina (<0.01% each). Mean monthly weight of digestive tract contents including empty stomachs ranged from 0.9 mg (April 2002) to 15 mg (November 2002; Table 6). Mean percent of empty stomachs by month was 9%.

Among animal taxa, aquatic insects were the most common food item, ranging in percent weight from 2.5% (November 2001) to 70% (May 2002). Amount of aquatic insects consumed was greater during the spring and summer and less during the fall and winter. Diptera was the most abundant aquatic insect consumed (78% by weight of aquatic insects) followed by Ephemeroptera (9.0%), Odonata (7.6%), Plecoptera (4.3%) and Trichoptera (1.6%). Terrestrial insects ranged in percent weight from 0 to 4.6% with adult dipterans being the most abundant terrestrial insect consumed (66%), followed by Coleoptera (34%) and Hemiptera (<0.1%). Collembola, Crustacea (Amphipoda and Ostracoda) and Hydracarina were rare (<2%). Although not a food item, percent weights of Cestoda ranged from 0 (December 2001 and January 2002) to 43% (September 2002). Amount of cestodes in the digestive tract typically were greater from June through September and less from October through May.

Among non-animal taxa, percent weight of detritus ranged from 3.9 (July 2002) to 75% (November 2001). Detritus was greater during the fall and winter and less during spring and summer. Percent weight of sand or silt ranged from <0.1 (March and May 2002) to 55% (February 2002). Plant material was minimal, occurring only in six individuals.

DISCUSSION

Notropis sabinae occurrence, abundance and density were not related consistently to multivariate habitat gradients within the sites sampled in this study, but were not randomly distributed within the study sites either. Overall, *N. sabinae* in Banita Creek and LaNana Bayou is a habitat generalist with affinities for shallow, moving water and rarely found in backwater or pool areas. Although our sampling methods did not allow for quantification of *N. sabinae* abundance or size segregation within geomorphic units, on several occasions we did observe spatial segregation of adult and juvenile fishes. In these instances, age-0 fish were more abundant over shallow, silt laden bedrock whereas adults were collected or observed over deeper, sandy areas within the same geomorphic unit. Moriarty and Winemiller (1997) documented a similar segregation pattern between adult and juvenile *N. sabinae* in Village Creek (Texas) with adults associated with deep sand bars and juveniles found in shallower areas of the stream. However, *N. sabinae* were not exclusively associated with sandy areas as previously reported by Gilbert (1978) and Moriarty and Winemiller (1997).

Notropis sabinae is a relatively fast growing species with a maximum life span of approximately 2.5 y. Individuals exhibit rapid growth rates and reach a maximum total length of approximately 52 mm during their first summer. The Banita Creek population is composed largely of age-1 fish from January until late summer but this age class steadily

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FIG. 3.—Monthly-length frequency histograms of *Notropis sabinae* collected from three sites on Banita Creek and one site on LaNana Bayou, Nacogdoches, Texas, from November 2001 through October 2002. Monthly collections were pooled across all sites. Dashed lines represent seasonal von Bertalanffy growth curve with parameters $K = 0.84$, $L_\infty = 68.0$, $t_0 = -0.03$, $t_s = 0.5$ and $C = 0.9$ and delineate mean total length for each age group
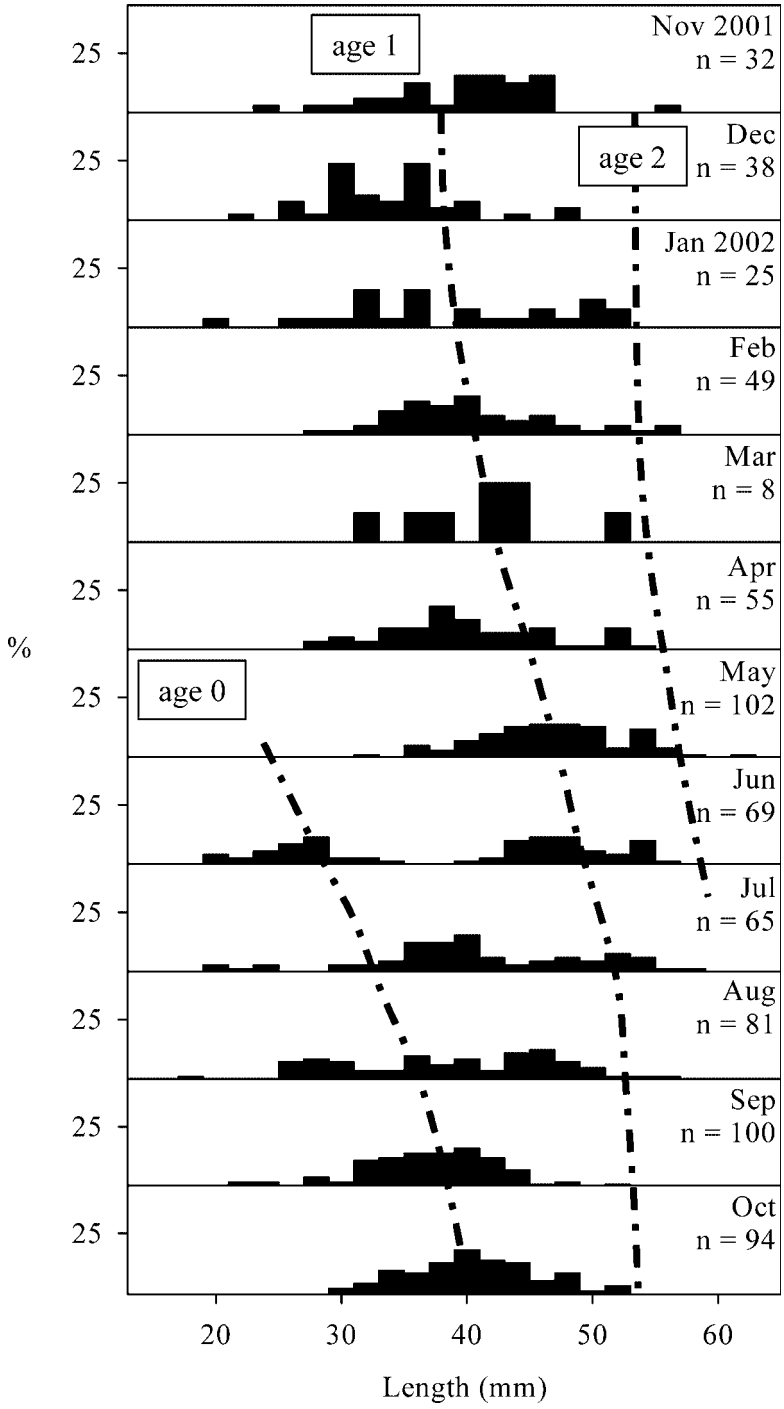
TABLE 5.—Catch per unit effort (# of individuals/m^2) and number of *Notropis sabinae* (n) collected from three sites on Banita Creek (Sites 1–3) and one site on LaNana Bayou (Site 4), Texas, from November 2001 through October 2002

| Month | Catch per unit effort (# of individuals/m^2) | | | |
	Site 1	Site 2	Site 3	Site 4
Nov.	— (0)	—	0.238 (124)	— (0)
Dec.	— (0)	0.011 (6)	0.043 (48)	— (0)
Jan.	— (0)	0.033 (20)	0.004 (4)	— (0)
Feb.	— (0)	0.085 (27)	0.021 (21)	0.005 (2)
Mar.	— (0)	0.005 (2)	0.015 (4)	0.001 (2)
Apr.	0.001 (1)	0.120 (32)	0.027 (22)	— (0)
May	0.048 (33)	0.242 (88)	0.060 (54)	0.013 (11)
Jun.	0.025 (16)	0.047 (14)	0.078 (50)	0.008 (9)
Jul.	0.004 (2)	0.022 (6)	0.035 (40)	0.030 (27)
Aug.	0.007 (3)	0.064 (17)	0.126 (110)	0.047 (39)
Sep.	0.027 (11)	0.083 (17)	0.194 (170)	0.106 (50)
Oct.	0.056 (15)	0.053 (16)	0.065 (48)	0.259 (85)

declines throughout its second year, resulting in very few age-2 fish the following year. These trends in size structure mirror those found by Heins (1981) for Bayou Anacoco, Louisiana, but differ from his findings of Big Cow Creek, Texas. The Big Cow Creek population consisted mostly of age-2 fish with a small percentage of age-1 fish.

Downstream drift of *Notropis sabinae* eggs or larvae was suggested by the first appearance of age-0 fish at downstream sites and absence at upstream sites until early fall. This pattern of downstream displacement is suggested for other stream fish (Heins and Baker, 1989) and is also suggested by the data presented by Heins (1981) for upper reaches of Big Cow Creek where large numbers of adult *N. sabinae* were found year round, but age-0 fish were noticeably absent until early fall. Thus, *N. sabinae* might employ downstream drift as a dispersal mechanism within the streams it inhabits. Downstream drift of eggs or larvae is a common and effective dispersal mechanism among fish species inhabiting variable stream systems (Bestgen *et al.*, 1989; Platania and Altenback, 1998) such as Banita Creek. However, this life history trait is susceptible to stream impediments that disrupt the return upstream and result in extirpation of species from upstream areas (Winston *et al.*, 1991; Wilde and Ostrand, 1999).

Observed temporal patterns in ovarian development, GSI, ova diameter size distribution and size at maturity suggest that *Notropis sabinae* is an early maturing species that releases multiple cohorts of eggs over a protracted spawning period. Ovarian condition and GSIs indicate that the main reproductive season extends from May to September with a few individuals continuing reproduction into early October. Three oocyte size classes were present within reproductively mature females, indicating production of multiple egg cohorts during the spawning period (Heins and Rabito, 1986). Heins (1981) found similar results for *N. sabinae* in the Sabine River drainage from December 1972 through November 1973; however, fishes in the Sabine River drainage became reproductively mature in April, one month earlier than those of Banita Creek and LaNana Bayou. Based on size-age inferences, all female *N. sabinae* are sexually mature by the end of their second summer (age 1). In addition, the presence of developing and mature ovaries of smaller individuals during early fall supports Heins (1981) suggestion that some individuals may reach reproductive maturity during their first summer (age-0). Age-0 reproduction has been suggested for
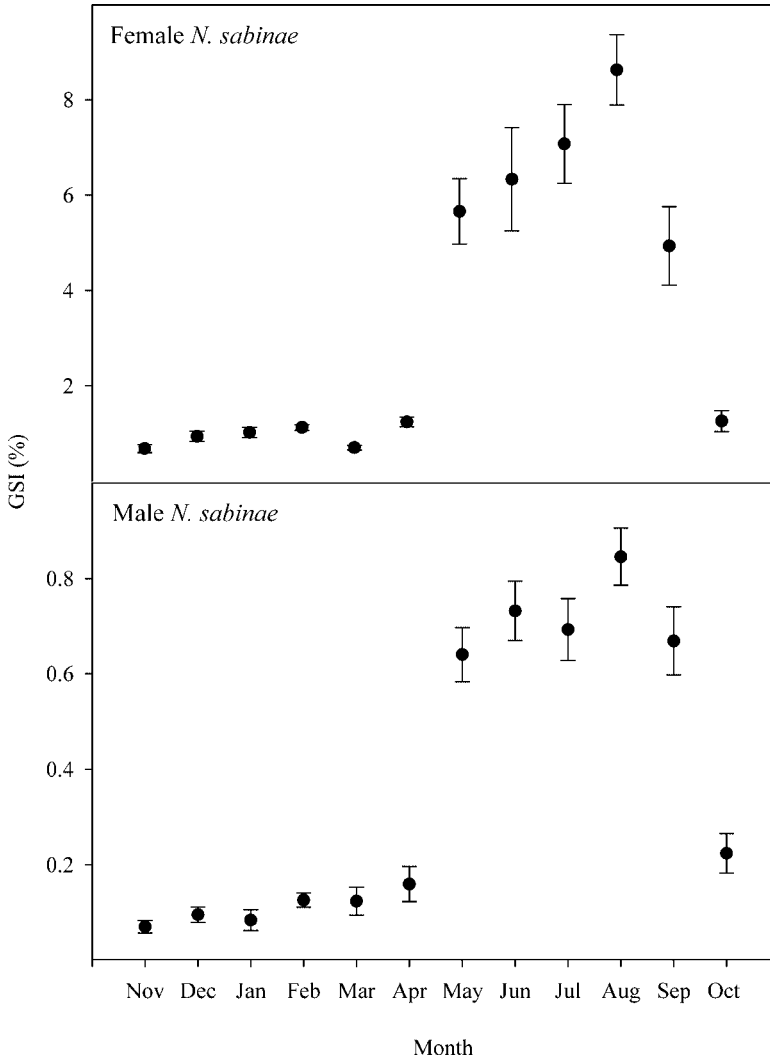
FIG. 4.—Mean (±SE) monthly gonadosomatic index (GSI) for female and male *Notropis sabinae* from Banita creek and LaNana Bayou, Nacogdoches, Texas, November 2001 through October 2002

several cyprinids, including *N. maculatus* (Cowell and Barnett, 1974) and *N. longirostris* (Heins and Clemmer, 1975), and documented in *Cyprinella lutrensis* (Marsh-Matthews *et al.*, 2002).

Early maturation, short life spans and extended spawning periods are life history traits shared by many *Notropis* fishes (Matthews *et al.*, 1978; Heins and Rabito, 1986; Platania and Altenbach, 1998). These traits allow rapid turnover and dispersal rates within and among streams and are characteristics of opportunistic species (Winemiller and Rose, 1992). Opportunistic life history strategies are advantageous for fishes that inhabit variable environments, allowing these species to quickly recolonize during natural variation or
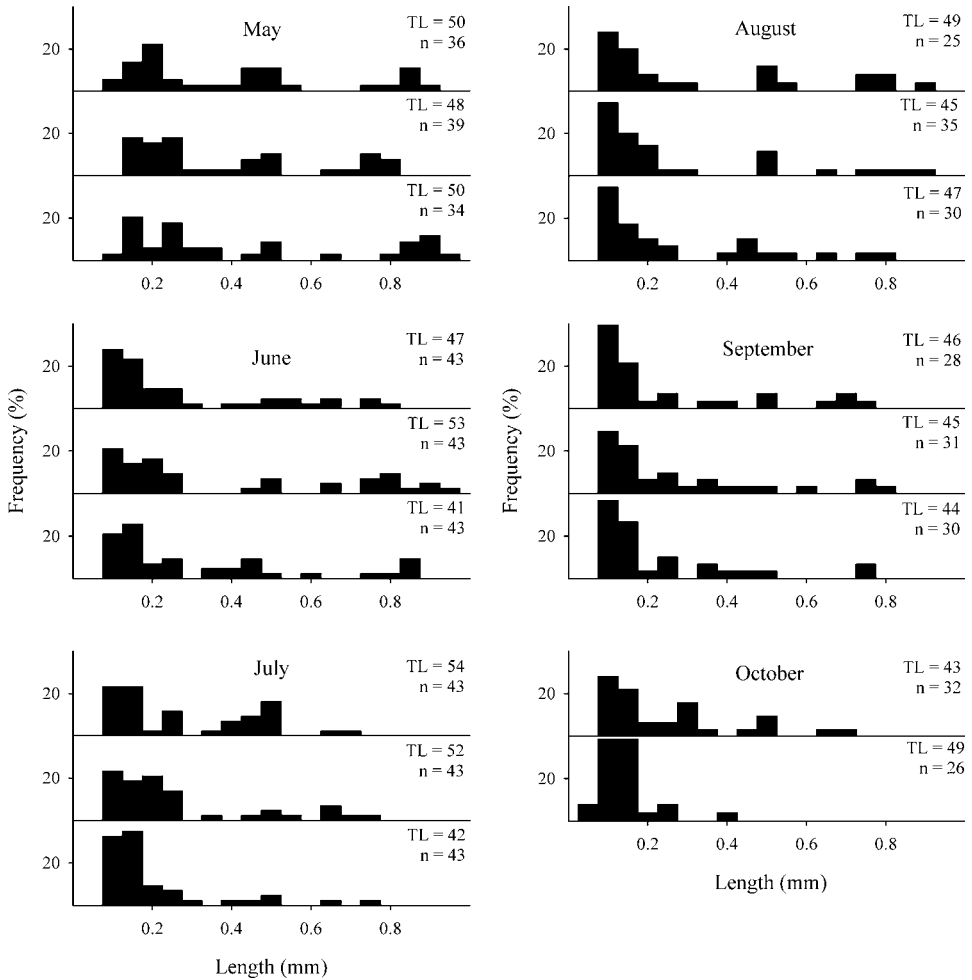
FIG. 5.—Monthly size-frequency distribution for ova diameters from three reproductively mature *Notropis sabinae* collected from May through September 2002. Ova diameters were measured for only two mature individuals for October 2002

disturbances in the environment. Upland streams in east Texas supporting *N. sabinae* populations are affected by frequent spates and periods of drought. Thus, the opportunistic characteristics of *N. sabinae* are ideal for fishes inhabiting these streams.

Corresponding with these opportunistic traits, *Notropis sabinae* is a generalist feeder. Detritus was abundant in their diet from October through February, whereas aquatic insects were abundant from March through September. This observed shift from detritus to aquatic insects might be related to increases in insect availability during the spring. Conversely, this shift may stem from a larger proportion of older individuals collected during March and September, suggesting ontological diet changes from soft organic matter with sufficient nutrients (Ahlgren, 1990) to food items that are more difficult to masticate and process (Heins and Clemmer, 1975). The abundance of aquatic insects, scarcity of terrestrial insects

TABLE 6.—Mean total weight (mg), percent empty stomachs and percent of food and other items found in the stomachs of *Notropis sabinae* collected from three sites on Banita Creek (Sites 1–3) and one site on LaNana Bayou (Site 4), Texas, from November 2001 through October 2002

Month	N	Mean total weight (mg)	Empty stomachs (%)	Aquatic insects (%)	Terrestrial insects (%)	Unidentified insects (%)	Collembola (%)	Crustacean (%)	Hydracarina (%)	Plant material (%)	Sand/Silt (%)	Detritus (%)	Cestoda (%)
Nov.	10	14.54	16.7	2.5	0.7	0.7	—	—	—	—	11.1	74.5	10.2
Dec.	17	3.85	10.5	37.3	—	4.9	—	—	—	—	4.0	53.8	—
Jan. 2002	12	3.17	25.0	15.3	—	11.6	<0.1	1.6	—	—	2.4	69.1	—
Feb.	40	7.52	—	25.4	1.9	1.9	<0.1	0.1	—	0.2	54.9	14.9	0.8
Mar.	11	2.77	—	45.7	3.3	1.3	—	—	—	—	<0.1	9.4	40.3
Apr.	24	0.88	—	46.8	—	5.8	—	—	<0.1	0.5	0.6	35.9	10.5
May	49	2.53	7.5	70.0	1.7	4.4	—	—	—	—	<0.1	14.5	9.5
Jun.	25	1.75	28.6	50.0	3.9	1.9	—	<0.1	—	—	1.8	14.5	27.9
Jul.	32	1.62	8.6	43.4	4.6	—	0.6	—	—	0.6	10.4	3.9	36.5
Aug.	28	1.86	9.7	44.2	3.7	—	—	—	—	—	0.2	11.6	40.4
Sep.	25	1.73	7.4	42.0	0.7	—	—	—	—	—	9.7	4.4	43.1
Oct.	36	0.92	10.0	56.0	0.9	—	—	1.7	<0.1	<0.1	9.0	22.3	9.9

and frequency of sand and silt in their stomachs indicate *N. sabinae* is a bottom feeder (Heins and Clemmer, 1975; Wilde *et al.*, 2001) as suggested by Pflieger (1997).

Reported declines in *Notropis sabinae* abundance and distribution are similar to the declines of many other cyprinids. Although declines in *N. sabinae* are not yet associated with habitat alterations, localized extirpations caused by anthropogenic alterations to habitat and flow regime (Anderson *et al.*, 1995; Richter *et al.*, 1997; Warren *et al.*, 2000) are common among stream fishes and often most detrimental to fishes with narrow distributional ranges (Meffe and Carroll, 1997). Many of these endemic and geographically limited species are adapted to highly variable systems. Major habitat or flow alterations may disrupt this natural variability and change the structure and function of the entire system (Ligon *et al.*, 1995; Bunn and Arthington, 2002). Endemic or native species may be affected directly by the physical changes or indirectly by increased biotic interactions with exotic species or native invaders (Winston *et al.*, 1991; Bonner and Wilde, 2000; Scott and Helfman, 2001; Bunn and Arthington, 2002).

Surprisingly, the *Notropis sabinae* population in Banita Creek and LaNana Bayou has persisted through time in this highly impacted urban stream. Urbanization has been associated with riparian loss, increased runoff and siltation, altered flow regimes and nutrient loading (Weaver and Garman, 1994; Paul and Meyer, 2001) and is often detrimental to native stream fishes (Weaver and Garman, 1994; Wang and Kanehl, 2001; Wang *et al.*, 2003). However, *N. sabinae* is relatively abundant in even the most urbanized areas of Banita Creek and LaNana Bayou. Based on their life history and generalist habitat and feeding habits reported herein, we hypothesize that *N. sabinae* persistence in this and possibly other highly impacted streams is not only attributed to sufficient resiliency and tolerance to small scale perturbations, but also to an intact riverscape (Fausch *et al.*, 2002). Conversely, we predict *N. sabinae* abundance and distribution would decline in streams with fragmented riverscapes regardless of the level of small scale anthropogenic perturbations.

LITERATURE CITED

AHLGREN, M. O. 1990. Nutritional significance of facultative detritivory to the juvenile white sucker (*Catostomus commersoni*). *Can. J. Fish. Aquat. Sci.,* **47**:49–54.

ANDERSON, A. A., C. HUBBS, K. O. WINEMILLER AND R. J. EDWARDS. 1995. Texas freshwater fish assemblages following three decades of environmental change. *Southwest. Nat.,* **40**:314–321.

ARMANTROUT, N. B. (compiler). 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland. 136 p.

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. *Am. Midl. Nat.,* **122**:228–235.

BONNER, T. H. AND G. R. WILDE. 2000. Changes in the Canadian River fish assemblage associated with reservoir construction. *J. Freshwater Ecol.,* **15**:189–198.

BUNN, S. E. AND A. H. ARTHINGTON. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environ. Manage.,* **30**:492–507.

COWELL, B. C. AND B. S. BARNETT. 1974. Life history of the taillight shiner, *Notropis maculatus*, in central Florida. *Am. Midl. Nat.,* **91**:282–293.

DEVRIES, D. R. AND R. V. FRIE. 1996. Determination of age and growth, p. 483–512. *In:* B. R. Murphy and D. W. Willis (eds.). Fisheries techniques, 2nd ed. American Fisheries Society, Bethesda, Maryland.

DICKENS, F. A. 1950. A distributional study of fishes in the Nacogdoches area. Masters Thesis, Stephen F. Austin State College, Nacogdoches, Texas. 83 p.

DOUGLAS, N. H. 1974. Freshwater fishes of Louisiana. Claitor's Publishing Division, Baton Rouge, Louisiana. 443 p.

FAUSCH, K. D., C. E. TORGERSEN, C. V. BAXTER AND H. W. LI. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. *Bioscience,* **52**:1–16.

GOLDSTEIN, R. M. AND M. R. MEADOR. 2004. Comparisons of fish species traits from small streams to large rivers. *Trans. Am. Fish. Soc.,* **133**:971–983.

GILBERT, C. R. 1978. *Notropis sabinae*, p. 304. *In:* D. S. Lee, C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister and J. R. Stauffer, Jr. (eds.). Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh, North Carolina.

HEINS, D. C. 1981. Life history pattern of *Notropis sabinae* (Pisces: Cyprinidae) in the lower Sabine River drainage of Louisiana and Texas. *Tulane Studies Zool. Bot.,* **22**:67–84.

———— AND J. A. BAKER. 1993. Reproductive biology of the brighteye darter, *Etheostoma lynceum* (Teleostei: Percidae), from the Homochitto River, Mississippi. *Ichthyol. Explor. Freshwaters,* **4**:11–20.

———— AND ———— 1989. Growth, population structure, and reproduction of the Percid fish *Percina vigil. Copeia,* **1989**:727–736.

———— AND F. G. RABITO, JR. 1986. Spawning performance in North American minnows: direct evidence of the occurrence of multiple clutches in the genus *Notropis. J. Fish. Biol.,* **28**:343–357.

———— AND G. H. CLEMMER. 1975. Ecology, foods, and feeding of the longnose shiner, *Notropis longirostris* (Hay), in Mississippi. *Am. Midl. Nat.,* **94**:284–295.

HUBBS, C., R. J. EDWARDS AND G. P. GARRET. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. *Tex. J. Sci.,* **43**(Supplement):1–56.

KIRKWOOD, G. P., R. AUKLAND AND S. J. ZARA. 2001. Length frequency distribution (LFDA), Version 5.0. MRAG Ltd., London, UK.

KREBS, C. J. 1999. Ecological methodology, 2nd ed. Addison-Welsey Educational Publishers, Inc., Menlo Park, California. 620 p.

LIGON, F. K., W. E. DIETRICH AND W. J. TRUSH. 1995. Downstream ecological effects of dams. *Bioscience,* **45**:183–192.

MARSH-MATTHEWS, E., W. J. MATTHEWS, K. B. GIDO AND R. L. MARSH. 2002. Reproduction by young-of-year red shiner (*Cyprinella lutrensis*) and its implications for invasion success. *Southwest. Nat.,* **47**:605–610.

MATTHEWS, W. J., W. D. SHEPARD AND L. G. HILL. 1978. Aspects of the ecology of the duskystripe shiner, *Notropis pilsbryi*, (Cypriniformes, Cyprinidae), in an Ozark stream. *Am. Midl. Nat.,* **100**:247–252.

MEFFE, G. K. AND C. R. CARROLL. 1997. Principles of conservation biology, 2nd ed. Sinaurer Associates, Inc., Sunderland, Massachusetts. 729 p.

MORIARTY, L. J. AND K. O. WINEMILLER. 1997. Spatial and temporal variation in fish assemblage structure in Village Creek, Hardin County, Texas. *Tex. J. Sci.,* **49**:85–110.

PAUL, J. M. AND J. L. MEYER. 2001. Streams in the urban landscape. *Annu. Rev. Ecol. Syst.,* **32**:333–365.

PFLIEGER, W. L. 1997. The fishes of Missouri. Missouri Department of Conservation, Jefferson City, Missouri. 372 p.

PHILLIP, D. A. 1993. Reproduction and feeding of the mountain mullet in Trinidad, West Indies. *Environ. Biol. Fishes.,* **37**:47–55.

PLATANIA, S. P. AND C. S. ALTENBACH. 1998. Reproductive strategies and egg types of seven Rio Grande basin cyprinids. *Copeia,* **3**:559–569.

QUINN, G. P. AND M. J. KEOUGH. 2002. Experimental design and data analysis for biologists. Cambridge University Press, UK. 537 p.

RICHTER, B. D., D. P. BRAUN, M. A. MENDELSON AND L. MASTER. 1997. Threats to imperiled freshwater fauna. *Cons. Bio.,* **11**:1081–1093.

ROBISON, H. W. AND T. M. BUCHANAN. 1988. Fishes of Arkansas. University of Arkansas Press, Fayetteville, Arkansas. 536 p.

ROSS, S. T. 2001. Inland fishes of Mississippi. University Press of Mississippi, Jackson, Mississippi. 624 p.

SCOTT, M. C. AND G. S. HELFMAN. 2001. Native invasions, homogenization, and the mismeasure of integrity of fish assemblages. *Fisheries,* **26**:6–15.

TAYLOR, C. M. AND P. W. LIENESCH. 1996. Regional parapatry of the congeneric cyprinids *Lythrurus snelsoni* and *L. umbratilis*: species replacement along a complex environmental gradient. *Copeia,* **1996**:493–497.

——— AND M. L. WARREN, JR. 2001. Dynamics in species composition of stream fish assemblages: environmental variability and nested subsets. *Ecology,* **82**:2320–2330.

WANG, L., J. LYONS AND P. KANEHL. 2003. Impacts of urban land cover on trout streams in Wisconsin and Minnesota. *Trans. Am. Fish. Soc.,* **132**:825–839.

——— AND P. KANEHL. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environ. Manage.,* **28**:255–266.

WARREN, M. L., JR., B. M. BURR, S. J. WALSH, H. L. BART, JR., R. C. CASHNIER, D. A. ETNIER, B. J. FREEMAN, B. R. KUHAJDA, R. L. MAYDEN, H. W. ROBISON, S. T. ROSS AND W. C. STARNES. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. *Fisheries,* **25**:7–31.

WEAVER, L. A. AND G. C. GARMAN. 1994. Urbanization of a watershed and historical changes in a stream fish assemblage. *Trans. Am. Fish. Soc.,* **123**:162–172.

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. *J. Freshw. Ecol.,* **16**:403–410.

——— AND K. G. OSTRAND. 1999. Changes in the fish assemblage of an intermittent prairie stream upstream from a Texas impoundment. *Tex. J. Sci.,* **51**:203–210.

WINEMILLER, K. O. AND K. A. ROSE. 1992. Patterns of life-history diversification in North American fishes: implications for population regulation. *Can. J. Fish. Aquat. Sci.,* **49**:2196–2218.

WINSTON, M. R., C. M. TAYLOR AND J. PIGG. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. *Trans. Am. Fish. Soc.,* **120**:98–105.

ZAR, J. H. 1999. Biostatistical analysis, 2nd ed. Prentice Hall, Upper Saddle River, New Jersey. 663 p.