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Distribution, density, and population dynamics of the Anthony Riversnail (*Athearnia anthonyi*) in Limestone Creek, Limestone County, Alabama

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Abstract: *Athearnia anthonyi* (Redfield, 1854) is a federally endangered gastropod endemic to the Tennessee River drainage in Alabama and Tennessee. It occurs in only three small populations, the most robust in Limestone Creek, Limestone County, Alabama. In 1996, this population was restricted to the lower 14.5 km of unimpounded stream, confined to riffle and run habitats. A follow-up survey in 2006 suggested no change in range within Limestone Creek. In 1996-97, quantitative data were collected from 4 selected sites in the reach and mean *A. anthonyi* density was 83.9 ± 9.9 *SE* per m^2 ($N = 90$). Although density did not vary among months, the proportion of individuals within four size classes differed. New recruits appeared in the population between May and July, and a significant die-off of older individuals occurred during the same period. Many individuals were suspected of having at least two breeding seasons. Increasing urbanization within the Limestone Creek watershed necessitates monitoring of *A. anthonyi*.

Key words: endangered species, recruitment, freshwater gastropod

Freshwater snails of the family Pleuroceridae comprise a prominent element of the benthic fauna of many southeastern U.S. streams (Richardson *et al.* 1988, Brown *et al*. 2008). Species within the family are generally large compared to other benthic organisms and often occur in high densities. However, many species have undergone dramatic declines during the past century, following impoundment of major rivers and other negative impacts on their habitats (Lydeard *et al.* 2004, Lysne *et al.* 2008). Nowhere have these declines been more evident than Alabama. Of approx. 112 pleurocerid species known from the state, 29 are considered extinct and five are federally protected (Mirarchi 2004).

Athearnia anthonyi (Redfield, 1854) (= *Leptoxis crassa anthonyi*, Anthony Riversnail) is a pleurocerid that has undergone drastic declines during the past century and was listed as endangered under the federal Endangered Species Act in 1994 (Federal Register 1994). This species is endemic to the Tennessee River drainage and was historically widespread in upper and middle reaches of the Tennessee River proper, ranging from Knoxville in eastern Tennessee, downstream to Muscle Shoals in northwestern Alabama, as well as in the lower reaches of major tributaries (Goodrich 1931, Burch 1989, Garner 2004). Three extant populations are currently known (Minton and Savarese 2005). Two of the remaining populations occur in close proximity, in lower reaches of the Sequatchie River and adjacent Tennessee River in the Nickajack Dam tailwaters, Marion County, Tennessee, and Jackson County, Alabama. The third and most robust population is found in Limestone Creek, Limestone County, Alabama. In 2001, a Nonessential Experimental Population (NEP) was designated for the Tennessee River in Wilson Dam tailwaters by the U. S. Fish and Wildlife Service (Federal Register 2001). From 2003 to 2008 a total of 4,000 *A. anthonyi* from the Limestone Creek population were released into the NEP area at Tennessee River mile (TRM) 249. The first observation of reproduction among the reintroduced snails was recorded during late summer 2008 (Garner, pers. obs.).

Although the locations of extant *Athearnia anthonyi* populations are known, little has been published about the species, and life history information is needed for its recovery (U. S. Fish and Wildlife Service 1997). Therefore, the objectives of this research were to: (1) determine distributional limits of *A. anthonyi* in Limestone Creek, (2) estimate density within a reach of Limestone Creek to better understand population vigor and provide baseline data for future studies, and (3) obtain information concerning population recruitment and dynamics.

MATERIALS AND METHODS

Habitat description

Limestone Creek is approx. 72 km long and has a drainage area of 290 km^2. Most of the drainage lies within Limestone County, Alabama, but headwaters originate in Madison County, Alabama, and Lincoln County, Tennessee. It is a third order stream within the Tennessee Valley District of the Interior Low Plateau Physiographic Province (Sapp and

Emplaincourt 1975). Underlying geology is composed of Fort Payne Chert and Tuscumbia Limestone, with some upstream reaches containing exposed sediments of the Ordovician System (Osborne *et al.* 1988, Szabo *et al.* 1988). Substrata of runs and riffles are mostly gravel with interstitial silt whereas pools and marginal areas often have deposits of mud and beds of Waterwillow (*Justicia americana*). Accumulations of leafy detritus are often encountered in pools. Exposed bedrock occurs at some sites, but outcrops are generally not extensive. Land use surrounding Limestone Creek is primarily agricultural, with scattered forested areas, but residential areas have increased considerably in the last decade. Riparian vegetation is generally intact and banks are stable. Canopy cover in most reaches is extensive, spanning the stream in many areas. The stream empties into Limestone Creek embayment which enters Wheeler Reservoir of the Tennessee River at TRM 311 (Fig. 1).

Qualitative survey methods

A qualitative survey to determine the distribution *Athearnia anthonyi* in Limestone Creek was performed primarily at road access points 7 May-24 June 1996. A 9-km float trip, employing mask and snorkel searches in runs and riffles at approx. 25 sites, was carried out between Limestone Creek mile (LCM) 14.6 (Limestone County Rd. 24) and LCM 9.0 (Limestone County Road 12) (Fig. 1). This survey provided access to sites between bridge crossings and allowed determination of the upstream limit of *A. anthonyi*.

A more extensive qualitative survey was conducted in August and September 2006 at 13 road access points between LCM 4.5 and LCM 38 (Table 1, Fig.1). The site identified as the upstream limit of *Athearnia anthonyi* in 1996 was not accessible during the 2006 survey. However, a visit to LCM 12.5 was made in December 2007 to confirm the continued presence of the species. Qualitative sampling in reaches up

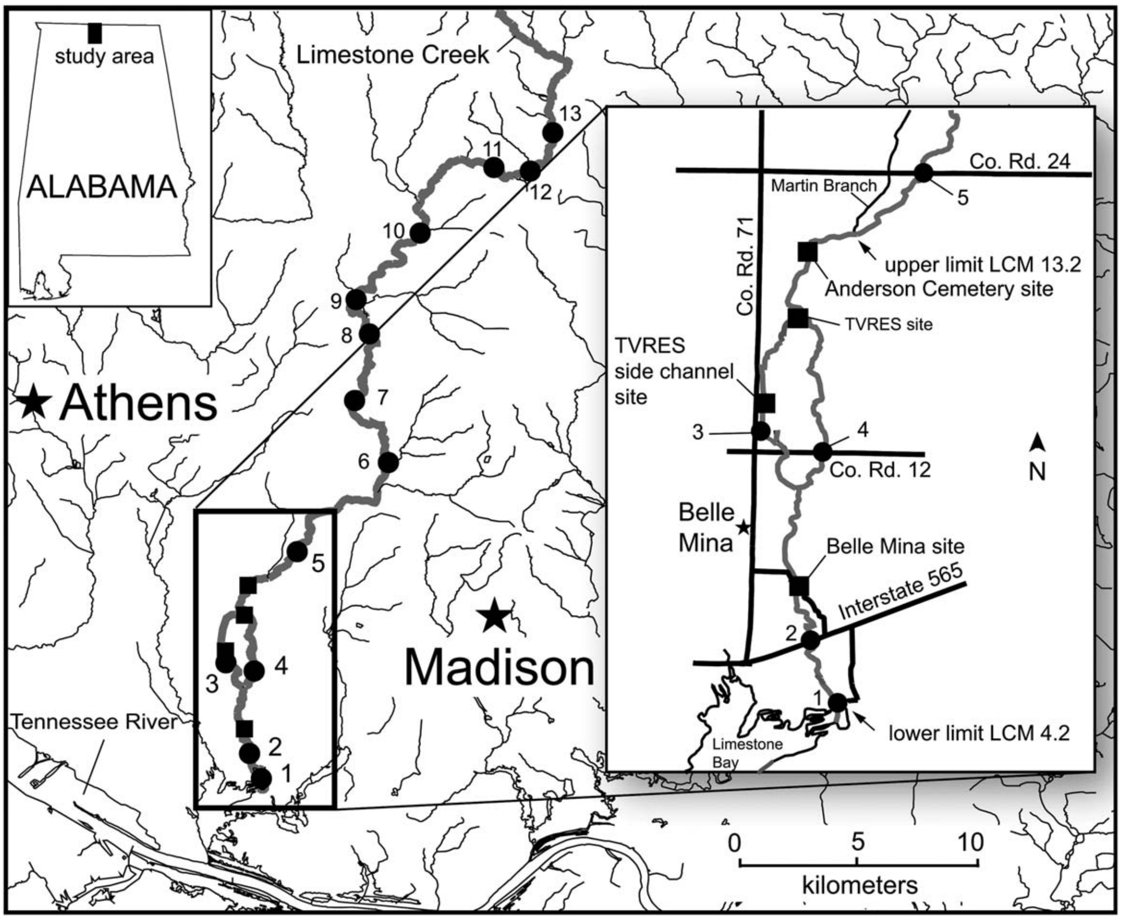

Figure 1. Study area showing survey sites on Limestone Creek, Limestone and Madison counties, Alabama. Circles denote road crossing survey sites and squares denote sites used to obtain density and demographic estimates. Inset shows more specific location of density and demographic estimate sites. Survey site numbers correspond to those used in Table 1.

Table 1. Sample localities and survey results from 13 sites on Limestone Creek, Limestone and Madison counties, Alabama. obs, number of observers.

Sample ID	Date	Latitude (°N)	Longitude (°W)	Individuals/hr/obs	obs	time (min)
LC1	14-Aug-2006	34°37'09.26"	86°51'40.78"	0	3	72
LC2	7-Aug-2006	34°37'53.72"	86°52'01.06"	500+	2	60
LC3	14-Aug-2006	34°40'31.36"	86°52'42.56"	500+	3	83
LC4	14-Aug-2006	34°40'17.72"	86°51'52.99"	2	3	49
LC5	14-Aug-2006	34°43'46.38"	86°50'37.43"	0	3	63
LC6	18-Aug-2006	34°46'22.33"	86°47'58.16"	0	3	40
LC7	18-Aug-2006	34°48'10.40"	86°48'57.67"	0	3	50
LC8	18-Aug-2006	34°50'06.36"	86°48'31.28"	0	3	35
LC9	25-Aug-2006	34°51'06.66"	86°48'54.68"	0	2	65
LC10	25-Aug-2006	34°53'03.30"	86°47'02.18"	0	2	55
LC11	1-Sep-2006	34°54'57.96"	86°44'54.17"	0	3	70
LC12	1-Sep-2006	34°54'51.80"	86°43'50.19"	0	3	70
LC13	1-Sep-2006	34°55'58.87"	86°43'10.99"	0	2	55

to 100 m long was carried out for an average of 2.65 person hours per site (range 1.75–4.15, N = 13). Most *A. anthonyi* were located by visually searching the stream bottom, by collecting substratum with a 1-mm mesh dipnet, or by hand and sorting them in a white pan.

Quantitative methods

Quantitative data were collected at four sites, selected based on presence of *Athearnia anthonyi* and stream accessibility. Sites were located at LCM 6.7 (34°38'36.60"N, 86°52' 9.84"W) near Belle Mina, LCM 11.1 (34°41'55.32"N, 86°52'9.83"W) on the Tennessee Valley Research and Extension Station (TVRES), LCM 12.4 (34°42'46.80"N, 86°52'4.08"W) near Anderson Cemetery and in an artificial side channel also located on the TVRES [approx. adjacent to LCM 9.5] (34°40'52.31"N, 86°52'43.31"W), all within Limestone County, Alabama (Fig. 1). Since studies of other pleurocerids (Houp 1970, Miller-Way and Way 1989, Huryn *et al*. 1994) found little growth and reproductive activity during winter months, the sites were sampled in May and July 1996, and in May, July, and September 1997. Because some sites were not sampled for all three months [TVRES site (September only), Anderson Cemetery (July and September only), Belle Mina (May and September only)], data from all four sites were pooled to characterize the population within this relatively small reach (approximately 9 km).

At each site and sampling interval, three samples were collected one to three meters from both banks (depending on stream width and marginal depths) and at midstream for a total of nine samples per visit. Each sample was collected using a Surber sampler (0.09 m^2), from which all substrate was removed to a depth of approx. 10 cm. The material was washed in a brass 2-mm sieve with creek water and contents placed into a shallow white pan. Due to the federal protection of *Athearnia anthonyi*, all samples were processed and snails enumerated and measured streamside. Each sample was reexamined by a different worker as a quality control measure. Since the tip of the spire was often eroded in larger individuals, width measurements were used to determine size class. Width was defined as the greatest distance between outer surfaces of the body whorl as measured on the same plane as the aperture. Measurements were made to the nearest millimeter using dial calipers. All *A. anthonyi* were then returned to the area from which they were collected.

A one-way ANOVA was performed to compare temporal differences in snail densities. Size-frequency plots were used to analyze population dynamics. In addition, size frequency distributions per sample were compared among months by dividing individuals into four size classes based on maximum width measurements and size frequency plots. The percentage of individuals within each size cohort per sample was compared among months using a Kruskal-Wallis test.

RESULTS

During the 1996 qualitative survey, *Athearnia anthonyi* was found in Limestone Creek from near the mouth of Martin Branch, approx. LCM 13.2, downstream to the upstream limit of impoundment at LCM 4.2, a distance of 14.5 km (Fig. 1). In this reach, *A. anthonyi* was common to abundant (hundreds usually observed) in almost all riffles and runs. During the more extensive 2006 survey, *A. anthonyi* was found in roughly the same reach, from LCM 5.6 to LCM 9.0, and was confirmed to continue upstream to at least LCM 12.5 in 2007.

During quantitative sampling in 1996 and 1997 the mean density for all 4 sample locations and collection dates was 83.9 ± 9.9 *SE* per m^2 (N = 90). Although density varied somewhat among months (May: 88.6 ± 10.9, N = 27; July: 113.2 ± 28.8, N= 27; September: 58.4 ± 7.8, N = 36), differences were not significant (ANOVA, F = 2.7, P = 0.07).

Size-frequency distributions indicated that in May, sizes ranged from 5 to 16 mm with two clear peaks in frequency, one composed of 8–9 mm sized individuals and the other of 11–12 mm snails (Fig. 2). Also in May, on average, 93% of the samples contained individuals that ranged in size from 6–15 mm (Fig. 3). This changed dramatically in July when sizes ranged from 2–17 mm, and a third mode composed of 3 mm individuals occurred, with the two peaks noted from May less pronounced (Fig. 2). Examination of the 4 size classes in the July samples showed that the percentage of individuals in the 1–5 mm size class increased significantly (Chi-square test, χ^2 = 16.9, P = 0.0002), whereas individuals in the 11–15 mm size class decreased (χ^2 = 16.0, P = 0.0003) since May (Fig. 3). Little change in the percentages of the other two ages classes (6–10 mm and 16–20 mm) were noted between May and July (Fig. 3). Although the range of sizes in September was also large (3–18 mm), only one clear mode in frequency was noted (10 mm, Fig. 2). Also, the percentage of individuals in the 1–5 size class that was predominant in July decreased dramatically by September, and there was an increase in the percentage of snails in the 11–15 (χ^2 = 16.0, P = 0.0003) and 16–20 mm size class (χ^2 = 13. 2, P = 0.001) (Fig. 3). The percentage of individuals in the 6–10 mm size class from September was similar to those of the other two months (χ^2 = 1.6, P = 0.4) (Fig. 3).

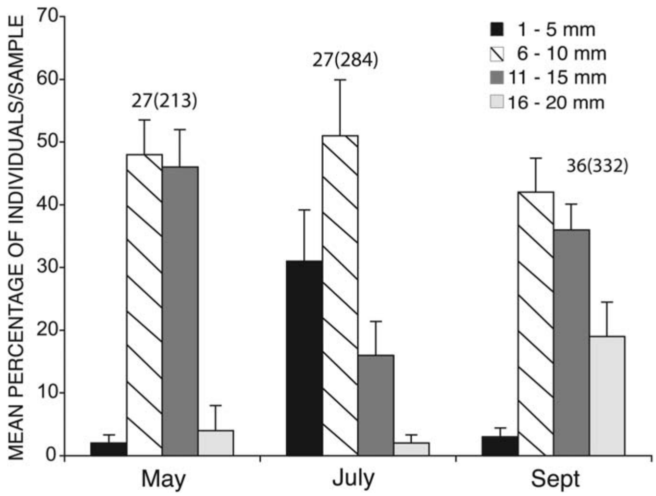

Figure 3. Mean percentage of individuals per sample for four shell width size classes for three months in 1996 and 1997. Numbers outside and inside parentheses above bars are sample sizes and number of individuals measured for each month, respectively. Error bars represent standard error.

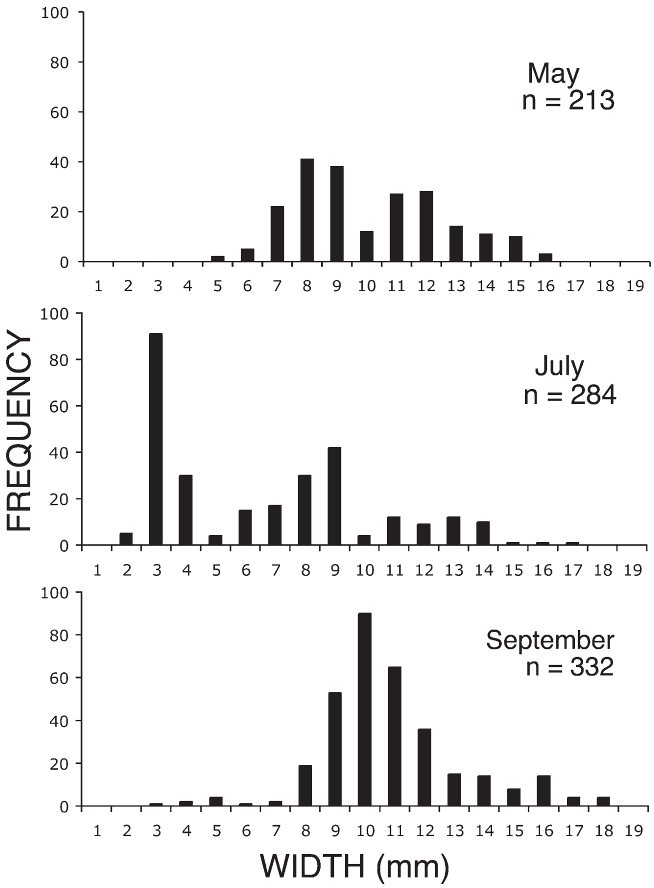

Figure 2. Size-frequency histograms indicating shell width range of *Athearnia anthonyi* for three months in 1996 and 1997 in Limestone Creek, Limestone County, Alabama.

DISCUSSION

The distribution of *Athearnia anthonyi* within Limestone Creek was similar between 1996 and 2006. Its absence from the lowermost site in 2006 is not surprising because it lies within the transition zone between free-flowing stream and reservoir and habitat is marginal (few individuals were found there in 1996). During the more extensive 2006 survey, *A. anthonyi* was not found above the site where it was noted in 1996, even though appropriate habitat (*i.e.,* riffles and runs) was examined. The upstream-most site for *A. anthonyi* in 1996 was again inaccessible during 2006, but since *A. anthonyi* was again observed just downstream in December 2007, little range reduction appears to have occurred between the two surveys. Factors responsible for limiting *A. anthonyi* to the lower 14 km of free-flowing stream are unclear.

Overall average density observed during 1996 quantitative sampling falls within the range of densities observed in other pleurocerid species. Examples of low pleurocerid densities reported in the literature were 24 and 38 per m^2 for *Pleurocera acuta* Rafinesque, 1831 and 38 per m^2 for *Elimia livescens* (Menke, 1830) (Dazo 1965, Houp 1970). In contrast, densities of *Elimia semicarinata* (Say, 1829) up to 1,706 per m^2 in specific habitats have been reported (Johnson and Brown 1997). Densities were not measured in 2006-07, but observations in suitable habitat suggested healthy populations (*i.e.*, all size classes represented, hundreds of individuals present).

The two peaks in the May size-frequency histogram suggest that at least two age cohorts were present: one composed of 1 year olds (*i.e.*, hatched the previous year) and another of at least two year olds. The presence of a third mode in the July size-frequency histogram and a significant increase in the proportion of 1-5 mm snails suggest that significant recruitment occurred between May and July. The timing of new-recruit appearance varies among pleurocerid species, but ranges from June and July to October (Houp 1970, Aldridge 1982, Miller-Way and Way 1989, Huryn *et al.* 1994, Richardson and Scheiring 1994). Van Cleave (1933) reported newly hatched *Pleurocera acuta* to measure 0.4 mm in diameter and surmised that they were hatched in June or July, but not collected until later, at a diameter of 6 mm. Some species have extended periods in which recruits appear, lasting three to four months, with numbers peaking toward the end of the period (Aldridge 1982, Richardson and Scheiring 1994). However, in this study it was difficult to tell whether small numbers of individuals in the 1–5 mm size class observed in May and September were new hatchlings or slow-growing individuals. Growth rates can be highly variable within some pleurocerid species (Huryn *et al.* 1994) and earlier-hatching captive pleurocerids often grow considerably faster than those that hatch later in the season (Paul Johnson, pers. comm.).

Although predation may have contributed to the drop in the proportion of 1–5 mm individuals between July and September (Haag and Warren 2006), many of the hatchlings likely grew into the 6–10 mm size class by September. This would explain why the proportion of 6–10 mm individuals was similar between July and September, even though the percentage of individuals in the 11–15 mm and 16–20 mm size classes also increased due to growth of the 6–10 and 11–15 mm cohorts of July, respectively. Rapid growth during early months, relative to the remainder of the life span, has been reported for other pleurocerids (Dazo 1965, Stiven and Walton 1967, Richardson *et al.* 1988, Huryn *et al.* 1994).

The relatively high percentage of individuals in the 6 – 10 mm size class in May suggests that many individuals do not exceed 10 mm during their hatching year and this size class is composed primarily of year-old snails. Many of these 1 year olds apparently grew into the 11–15 mm size class by September. The significant decrease in frequency of individuals in the 11–15 mm size class between May and July suggests mortality of many individuals within the class. Magruder (1934) reported a die-off of *Pleurocera canaliculatum undulatum* (Say, 1829) in the spring. Some pleurocerid species are biennial, including *Leptoxis carinata* (Bruguière, 1792), *Leptoxis dilatata* (Conrad, 1835), and *Pleurocera acuta* (Houp 1970, Aldridge 1982, Miller-Way and Way 1989). However, some live even longer, such as *Elimia clara* (Anthony, 1854) and *Elimia cahawbensis* (Lea, 1861) that may live as long as 10 and 11 years, respectively (Richardson *et al.* 1988, Huryn *et al.* 1994), and *Leptoxis foremani* (Lea, 1843) which has lived 6+ years in captivity (Paul Johnson, pers. comm.). Data from this study are insufficient to specifically determine life span, but assuming that individuals mature by the end of their first year and reproduce until death, *A. anthonyi* has at least two breeding seasons. Variation in growth can make it difficult to identify older cohorts (Huryn *et al.* 1994). Mark-recapture studies are needed to help identify age cohorts and obtain longevity estimates for *A. anthonyi*.

Johnson and Brown (1997) found that the densities and population size structure of *E. semicarinata* varied with abiotic factors (*e.g.*, current velocity). However, limited sampling in this study prevented such comparisons for *A. anthonyi* and variation in habitat features among sites could have contributed to the temporal variation observed. More specific ecological research is needed to characterize *A. anthonyi* habitat requirements, and this study provides preliminary estimates for density, recruitment time, and demographics.

In summary, the distribution *Athearnia anthonyi* has remained stable over the past decade. Densities observed at four sites and from three months in 1996 and 1997 averaged 83.9 per m^2. New recruits appeared in the population between May and July, a significant die-off of older individuals occurred during the same period, and adults may have at least two breeding seasons. Regular monitoring will be required to protect the Limestone Creek population of *A. anthonyi* from rapid urbanization of its watershed. Preliminary observations indicate that *A. anthonyi* is most abundant in riffle and run habitats and therefore anthropogenic activities (*e.g.*, excessive irrigation, sedimentation, pollution) that affect these high-density habitats could be detrimental to the species. A better understanding of the ecological factors limiting *A. anthonyi* populations is thus needed to help in the species recovery and to identify sites for reintroduction efforts (U. S. Fish and Wildlife 1997).

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