

A NEW SPECIES OF PERENNIBRANCHIATE SALAMANDER (*EURYCEA*: PLETHODONTIDAE) FROM AUSTIN, TEXAS

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ABSTRACT: A new species of salamander of the genus *Eurycea* is described from Barton Springs, Austin, Texas, USA. The new species is known only from two hydrologically connected sets of springs in and adjacent to Austin's Barton Springs swimming pool. It is morphologically and biochemically distinct from all known species of plethodontids. The new species is endangered by its limited distribution in an environmentally sensitive ecosystem that is threatened by the direct and indirect impacts of human development, and population sizes appear to have been reduced significantly in the past two decades. Recent efforts to modify maintenance practices at Barton Springs Pool and to protect the Barton Springs Aquifer appear to have reversed this trend, but the species is still in critical danger of extinction.

Key words: Caudata; Plethodontidae; Hemidactyliini; *Eurycea sosorum* new species; Endangered species; Texas; Barton Springs

THE springs and caves of the Edwards Plateau region of central Texas constitute islands of habitat for numerous populations of aquatic organisms, including perennibranchiate hemidactyliine plethodontid salamanders of the genera *Eurycea* and *Typhlomolge*. This group of salamanders has been taxonomically problematic for many years, due largely to a combination of morphological conservatism, maintenance of larval morphologies in most members of the group, and the possibility of morphological parallelism or convergence in members of the group that occupy similar habitats (see Sweet, 1977, 1978, 1982, 1984, for reviews of the distribution and taxonomic treatments of this group). Most surface-dwelling, and many cave-dwelling, populations of perennibranchiate *Eurycea* in central Texas currently are assigned to the species *Eurycea neotenes* Bishop and Wright 1937. Several populations in this group occur in the rapidly expanding Austin metropolitan area and are threatened to varying extents by habitat degradation, urban runoff, and water pollution. The group of springs known as Barton Springs, which have been modified to form a spring-fed swimming pool in the City of Austin, constitute the only

known habitat for the new species of *Eurycea* described in this paper.

MATERIALS AND METHODS

We use the following abbreviations for morphological measurements: AG (axilla-groin length), ALL (anterior limb length, from anterior insertion to tip of third finger), ED (eye diameter; i.e., anterior-posterior diameter of the externally visible, dark disc of the eye), HLA (head length A: distance from tip of snout to center of gular fold), HLB (head length B: distance from tip of snout to posterior margin of eye), HLC (head length C: distance from tip of snout to posteriormost gill insertion), HLL (hind limb length, from groin to tip of third toe), HW (head width immediately posterior to jaw articulation), IOD (interocular distance), SL (standard length: distance from tip of snout to posterior margin of vent), and TL (tail length, from posterior margin of vent to tip). Abbreviations for collections are: BCB (Bryce C. Brown collection, Strecker Museum, Baylor University), MVZ (Museum of Vertebrate Zoology, University of California, Berkeley), and TNHC (Texas Natural History Collection of the Texas Memorial Museum, University of Texas, Austin).

For morphometric analyses, we used 23 alcohol-preserved specimens of the new species. For comparison, we used topotypical *Eurycea neotenes* from near Helotes, Bexar Co., plus representatives of several other surface-dwelling populations that are currently assigned to *E. neotenes* or are thought to be most closely related to that species (see Appendix I for list of specimens and localities). For convenience, we will refer to these populations as *E. neotenes* in this paper, although several species may be involved; we will address the status of *Eurycea neotenes* elsewhere. We chose populations from the region to the south of the Colorado River from Hays Co. through western Kendall Co., because this region includes populations that are most similar genetically to the new species based on our ongoing molecular studies. We also included representatives of *E. nana*, a surface-dwelling species from San Marcos Springs in Hays Co., which occurs in the same geographic region. Most morphometric characters that we used were the same as, or very similar to, those described by Sweet (1984). Measurements for morphometric analysis were made as follows: AG, SL, and TL were measured with dial calipers; ALL, HLA, HLB, HLC, HW, and IOD were measured using an ocular micrometer at $\times 7.5$ magnification; and ED was measured with an ocular micrometer at $\times 64$ magnification with backlighting. All measures were rounded to the nearest 0.1 mm for subsequent analyses except ED, which was rounded to the nearest 0.01 mm. We log-transformed (\log_{10}) all measures prior to analysis. We chose not to measure any individuals with SL < 22.5 mm; the vast majority of individuals used in the study were known or inferred (based on size) to be sexually mature. [It is possible that a few individuals measured were in the process of maturation.] We conducted a discriminant function analysis (DFA) using the MDA program in the BioStat II multivariate statistical package (Pimentel and Smith, 1986), and designated each population used for analysis as an a priori group, for a total of seven groups (see Appendix I for names and taxonomic status of these groups). We also requested a pos-

teriori assignments of individuals to the initially specified groups, based on Geisser classification probabilities (Geisser, 1977; Pimentel and Smith, 1986). For counts of costal grooves (not included in morphometric analyses), we followed Burger et al. (1950) and assumed the presence of no more than one groove in the axilla and in the groin; in some specimens these grooves were indistinct. For osteological examination, two specimens were cleared and double-stained with Alizarin Red and Alcian Blue, following the protocol given by Dingerkus and Uhler (1977).

We used standard methods of horizontal starch-gel electrophoresis (Murphy et al., 1990) to resolve the products of 25 enzyme-encoding loci for 10 individuals of the new species. This work is part of an ongoing, broad-scale study of relationships among central Texas hemidactyliine plethodontids of the genera *Eurycea* and *Typhlomolge*; thus far we have collected allozyme data for approximately 300 individuals from 49 populations from throughout the Edwards Plateau region of central Texas. Further details of electrophoretic methods, and data for other members of the group, will be presented elsewhere. Genetic distances reported here were calculated using the BIOSYS-1 program (Swofford and Selander, 1981).

The habitat of the new species has been the focus of a recent initiative by the citizens of Austin to protect and preserve the Barton Springs Aquifer. In honor of the citizens of Austin and their desire to protect the habitat of the Barton Springs salamander (through their passage of the SOS, or Save Our Springs, Ordinance; see Etymology), we name the new species

Eurycea sosorum sp. nov.

Eurycea neotenes: Brown, 1950 (in part); Baker, 1961 (in part; mapped locality only).

Eurycea neotenes neotenes: Brown, 1967 (in part; mapped locality only).

Eurycea sp.: Sweet, 1978, 1984.

Holotype.—TNHC 51184 (field number PC/DMH 92-112) (Fig. 1), an adult male (based on external examination only)



FIG. 1.—*Eurycea sosorum* (TNHC 51184, holotype SL = 24.9 mm), from the outflow of the Parthenia outlet of Barton Springs in Barton Springs Pool, Zilker Park, Travis County, Texas.

collected from the outflow of Parthenia (Main) Springs in Barton Springs Pool, Zilker Park, Travis Co., Texas (30°15'49" N, 97°46'14" W) on the afternoon of 24 November 1992 by David M. Hillis, Paul T. Chippindale, Andrew H. Price, and Doyle Mosier at a depth of approximately 4–5 m, during a SCUBA dive.

Paratypes.—Collected 1946: TNHC 6317–6321. 1974: MVZ 122712–726. 1988–1992: TNHC 50915–32, 51180–83, 51185–92. Cleared-and-stained: TNHC 51178–79. All paratypes were collected at Barton Springs, Travis Co., Texas.

Etymology.—The species is named in honor of the citizens of Austin, Texas,

whose efforts to protect the quality of Barton Springs resulted in the passage of a citizens' aquifer-protection initiative in 1992. This initiative is known locally as the SOS (Save Our Springs) Ordinance, and its supporters are known as SOSers. The specific name *sosorum* is the plural mixed-gender genitive form of the acronym SOS.

Diagnosis.—*Eurycea sosorum* can be distinguished from other Texas perenni-branchiate *Eurycea* (currently assigned to *E. neotenes*, *E. nana*, and *E. tridentifera*, plus the putative hybrids known as *E. latitans* and *E. troglodytes*) by its unique combinations of both morphological and allozyme characters (allozyme data are not yet available for *E. latitans* and *E. troglodytes*). The slight "shovel-nose" that is apparent in most specimens is not as extreme as that of *E. tridentifera*, but does distinguish most individuals of *E. sosorum* from members of surface populations that currently are assigned to *E. neotenes* and *E. nana*. The eyes of *E. sosorum* are significantly reduced in comparison to individuals from other surface-dwelling populations of central Texas *Eurycea*. There was no overlap in ratios of eye diameter to standard length between *E. sosorum* and representatives of any of the other populations that we examined (Fig. 2). *Eurycea*

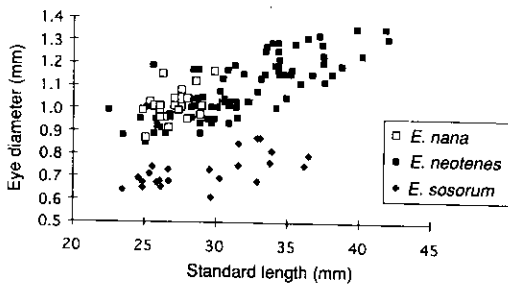


FIG. 2.—The relationship between eye diameter and standard length in *Eurycea neotenes* (filled squares), *E. nana* (open squares), and *E. sosorum* (filled diamonds).

TABLE 1.—Sample sizes and summaries of measurements (in millimeters) for specimens of *Eurycea* examined for morphometric variation. For each variable in each population, mean values \pm 1 SD are given, followed by ranges in parentheses. Refer to text for explanation of abbreviations for each measure. Sample sizes are in parentheses following population names.

Measure	Population/taxon						
	Boardhouse Springs (7) (<i>E. neotenes</i>)	Hélotés Creek Spring (19) (<i>E. neotenes</i>)	Comal Springs (19) (<i>E. neotenes</i>)	Fern Bank Spring (19) (<i>E. neotenes</i>)	Cibolo Creek Spring (19) (<i>E. neotenes</i>)	San Marcos Springs (21) (<i>E. nana</i>)	Barton Springs (23) (<i>E. scorum</i>)
SL	36.57 \pm 2.30 (34.1–40.2)	32.22 \pm 5.49 (22.5–42.0)	27.76 \pm 2.83 (23.5–34.3)	30.55 \pm 2.75 (25.6–35.9)	33.81 \pm 2.88 (28.3–38.1)	27.05 \pm 1.36 (24.9–29.9)	29.24 \pm 4.06 (23.5–36.5)
AG	20.66 \pm 1.42 (18.3–23.1)	18.98 \pm 3.50 (12.8–24.7)	15.20 \pm 1.87 (12.8–19.4)	17.73 \pm 1.71 (14.5–21.5)	18.94 \pm 1.69 (16.2–21.6)	15.44 \pm 0.97 (13.7–18.0)	15.97 \pm 2.81 (11.7–20.4)
TL	26.73 \pm 1.53 (20.1–31.4)	27.44 \pm 6.17 (17.8–38.3)	19.01 \pm 3.26 (12.0–27.8)	21.74 \pm 2.42 (17.5–25.4)	23.58 \pm 3.63 (17.1–32.0)	23.58 \pm 3.63 (17.1–32.0)	21.11 \pm 4.34 (13.6–30.7)
HLA	6.33 \pm 0.95 (5.5–8.2)	5.87 \pm 0.77 (4.6–7.7)	5.21 \pm 0.65 (4.2–6.7)	5.37 \pm 0.64 (4.2–6.8)	6.23 \pm 0.55 (5.4–7.0)	4.54 \pm 0.32 (4.0–5.0)	5.25 \pm 0.63 (4.0–6.5)
HLB	5.86 \pm 0.46 (5.1–6.4)	5.11 \pm 0.62 (4.0–6.5)	4.85 \pm 0.52 (3.7–5.9)	4.72 \pm 0.35 (4.1–5.4)	5.48 \pm 0.51 (4.7–6.4)	3.98 \pm 0.26 (3.6–4.5)	5.47 \pm 0.79 (4.1–7.4)
HCL	8.67 \pm 0.92 (7.6–10.4)	7.88 \pm 1.04 (6.1–9.7)	7.18 \pm 0.76 (5.5–8.7)	7.14 \pm 0.59 (6.1–8.3)	8.48 \pm 0.81 (7.2–10.0)	6.17 \pm 0.404 (5.6–7.4)	7.83 \pm 0.90 (5.9–9.9)
HW	4.97 \pm 0.47 (4.2–5.6)	4.70 \pm 0.69 (3.3–6.1)	4.34 \pm 0.42 (3.8–5.4)	4.45 \pm 0.514 (3.8–5.8)	4.94 \pm 0.53 (4.1–5.9)	3.64 \pm 0.36 (3.1–4.4)	4.38 \pm 0.67 (3.3–5.9)
IOD	1.64 \pm 0.22 (1.3–1.9)	1.37 \pm 0.24 (1.0–2.0)	1.28 \pm 0.15 (1.0–1.7)	1.45 \pm 0.204 (1.0–1.7)	1.66 \pm 0.25 (1.3–2.2)	1.13 \pm 0.17 (0.9–1.4)	1.60 \pm 0.25 (1.2–2.0)
HLL	6.84 \pm 0.57 (6.0–7.8)	6.64 \pm 1.12 (4.6–8.8)	5.37 \pm 0.45 (4.5–6.1)	5.39 \pm 0.48 (4.9–6.4)	6.43 \pm 0.58 (5.5–7.3)	5.12 \pm 0.40 (4.2–5.8)	6.96 \pm 0.91 (5.4–8.4)
ALL	6.39 \pm 0.76 (5.5–7.4)	6.02 \pm 0.92 (4.4–7.6)	4.85 \pm 0.46 (4.2–5.9)	5.14 \pm 0.36 (4.6–5.8)	5.86 \pm 0.55 (5.0–6.7)	4.72 \pm 0.35 (4.0–5.2)	6.44 \pm 0.81 (5.2–8.3)
ED	1.199 \pm 0.046 (1.15–1.28)	1.159 \pm 0.136 (0.99–1.35)	1.009 \pm 0.126 (0.85–1.27)	1.006 \pm 0.078 (0.89–1.19)	1.126 \pm 0.094 (0.96–1.32)	1.012 \pm 0.072 (0.87–1.16)	0.724 \pm 0.074 (0.61–0.87)

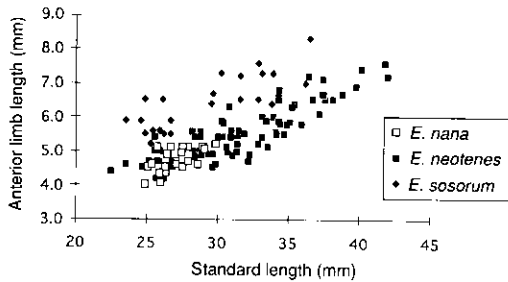


FIG. 3.—The relationship between anterior limb length and standard length in *Eurycea neotenes* (filled squares), *E. nana* (open squares), and *E. sosorum* (filled diamonds).

sosorum generally has proportionately longer limbs than other surface-dwelling central Texas *Eurycea* (Table 1, Fig. 3). For the 23 specimens that we measured, the ratio of anterior limb length to standard length ranged from 0.19–0.26 (\bar{x} = 0.22). In comparison, for the specimens of *E. neotenes* and *E. nana* that we examined, the highest ALL/SL ratios observed were 0.17–0.21 (\bar{x} = 0.19) in toptypical *E. neotenes* and 0.15–0.21 (\bar{x} = 0.18) in specimens from Comal Springs.

Most specimens of *E. sosorum* (88% of the 40 examined by Sweet, 1984) possess 16 presacral vertebrae; other surface-dwelling members of the *E. neotenes* species group typically have 17, although a few individuals in some populations possess 16 (Sweet, 1984; see also Variation and Osteology).

The dorsal coloration of most specimens is distinctive. *Eurycea sosorum* exhibits varying degrees of dorsal blotching and mottling (see Variation) due to an irregular mixture of melanophores, pigment gaps, and iridophores. Most individuals exhibit pale, irregular dorsal patches due to lack of melanophores; in addition, many individuals exhibit high concentrations of silvery-white iridophores that can be so dense that they partially obscure the melanophores. Although pigment loss occurs in other cave-dwelling members of the *Eurycea neotenes* group (Sweet, 1978), the combination of pigment gaps and frequently high concentrations of dorsal iridophores appears to be unique to *E. sosorum*.

Based on allozymes, *E. sosorum* can be distinguished from other populations of central Texas *Eurycea* and *Typhlomolge rathbuni* by a unique combination of alleles, including a high (80%) frequency novel allele at the Peptidase-A (E.C. 3.4.13.11; leucyl-L-glycine substrate) locus, and an apparently fixed allele at the Peptidase-D (E.C. 3.4.13.9; L-phenylalanyl-L-proline substrate) locus that otherwise is seen only in geographically distant populations that are currently referred to *E. neotenes*. Based on the preliminary allozyme data, the average Rogers' (1972) genetic distance between *E. sosorum* and the cluster of populations to which it is most similar is 0.169 (range: 0.114–0.210). Further details of the molecular work will be presented elsewhere in a broad-scale analysis of relationships of central Texas hemidactyliines.

Description of holotype.—SL = 24.9 mm). AG = 12.4 mm, ALL = 6.5 mm, HLA = 5.6 mm, HLB = 5.9 mm, HLC = 8.5 mm, HLL = 6.7 mm, HW = 4.9 mm, IOD = 1.7 mm, and ED = 0.64 mm. The eyes are very small (ED/SL = 0.026, ED/HW = 0.132). The head is noticeably deepest posterior to the eyes in lateral profile, giving the salamander a slight "shovel-nosed" appearance. The head is widest in dorsal aspect just anterior to the gill insertions; from there the outline of the head angles inward slightly to the level of the eyes, and angles inward slightly more from the eyes to the snout. Viewed from above, the snout is distinctly truncate. The three pairs of gills are well developed. There are 15 costal grooves. There are four fingers on each hand, and five toes on each foot. The tail is relatively short; the ventral tail fin is very narrow and in vertical profile is only clearly defined along the posterior third of the tail. The dorsal tail fin is well-developed, especially along the posterior third of the tail, and is clearly visible along the full length of the tail, from approximately the level of the hind limb insertions.

The dorsal pattern is variable and generally mottled with a combination of melanophores and areas lacking in dark pigment, presenting (in life) an overall color

of olive brown with a base color of yellowish cream; the effect is one of a coarse-grained, blotchy "salt-and-pepper" pattern. In ethanol, the overall color is brownish gray with off-white mottling. The trunk is finely and intensely speckled with melanophores; the ventral surface is creamy to translucent. Scattered melanophores invade the ventral surface, mainly in the areas immediately posterior to the gills and front limbs. The underside of the tail is mottled with melanophores. The limbs are unevenly mottled dorsally and the dorsal surfaces of the fingers and toes are speckled with melanophores. The ventral surfaces of the limbs are mainly clear, with occasional melanophores. The tail fins are finely speckled with melanophores. The dorsal surface of the tail displayed a narrow orange-yellow stripe from the level of the hind limb insertions to the tip in life. On the ventral surface of the tail, the living specimen had a narrow orange-yellow stripe from the posterior margin of the vent to the tip. Dark canthal lines are present, and a faint postorbital bar is apparent. The iris (in life) was golden with black mottling. There is a dark line of irregularly arranged melanophores immediately below the line of the mouth. A row of nine large, irregularly shaped paravertebral spots (areas in which dark pigment is lacking) is present on each side along the trunk between the limb insertions; these spots continue but are less well-defined on the tail. A pair of large parietal spots is present as an anterior extension of each row. Partially overlapping these spots is a row of smaller, silvery-white iridophores that appear under magnification as clusters of shiny "flakes" just below the surface of the skin; these were clearly visible only in life. The gills were bright red in life; they are speckled with scattered melanophores that are more evident in the preserved specimen.

Variation.—The maximum snout-vent length for *E. sosorum* measured in this study was 36.5 mm (total length 62.6 mm; TNHC 50918). Substantially larger individuals have been observed by us in the field, however. The width of the head varies considerably; Sweet (1978) initially de-

scribed the head as relatively small and narrow, but in some larger specimens the head appears proportionately very broad. Sweet (personal communication to P. Chippindale) has confirmed this observation. With this broadening of the head, the degree of truncation of the snout appears to diminish in some individuals. The number of costal grooves (which are often poorly defined and difficult to count) varies from 13 ($n = 1$) to 14 ($n = 11$) to 15 ($n = 13$) to 16 ($n = 1$). Sweet (1984) examined 40 specimens of *E. sosorum* and reported a strong mode of 16 presacral vertebrae: 35 individuals had this number, while two had 15 and three had 17. Degree of development of the tail fins varies considerably among individuals, although dorsal and ventral tail fins are usually clearly visible, at least along the posterior portion of the tail.

The dorsal color in life varies among individuals, from dark through medium gray, to purplish gray or gray-brown, to yellowish brown, to yellowish cream. Variation in color is also seen in preserved specimens, although this variation is much less pronounced, and in some older specimens the patterning is faded. The degree of dark dorsal mottling due to the presence of melanophores is highly variable, covering from roughly one-third of the dorsal surface to the entire dorsal surface [these estimates are based on our observations and those of Sweet (1978), who examined many additional specimens that cannot be located]. Most individuals display some variation of the characteristic mottled/coarse "salt-and-pepper" pattern; in some specimens, the melanophores are relatively widely dispersed, yielding an overall pale appearance, whereas in a few specimens they are so dense that these individuals appear dark gray in life. Dark canthal lines are distinguishable in most specimens, but are obscured by aggregations of melanophores in a few individuals. Many individuals exhibit a moderately well developed lateral row of pigment gaps, although these are indistinct or absent in some animals. The concentration of dorsal and lateral iridophores is highly variable; in life, most individuals possess a lateral row of

iridophores, and some individuals exhibit areas of silvery white dorsal pigmentation due to the presence of high concentrations of iridophores. Iridophores have been visible in varying concentrations in nearly all the live specimens that we have examined. The iridophores quickly fade in preservative (apparently during formalin fixation), so they may be difficult or impossible to discern in museum specimens.

Osteology.—Two cleared and double-stained specimens (TNHC 51178 and 51179, standard lengths = 30.4 and 32.6 mm, respectively) were examined with reference to characters described by Wake (1966), Mitchell and Smith (1972), and Sweet (1977). Maxillae, septomaxillae, nasals, and prefrontals are absent. Orbitosphenoids are present. The frontoparietal fontanelle is very extensive in both specimens. The frontals are elongate; their posterior margins are somewhat rounded and overlap the parietals, while the tapering anterior ends appear to be overlapped by the frontal processes of the premaxillae. The partes dentales of the premaxillae are fused together, but the frontal processes of the premaxillae are separate throughout their lengths. The vomer and palatopterygoid are dentate and not fused to each other. The parasphenoid lacks tooth patches in both specimens, and the tooth-bearing coronoid is clearly visible in both. The elements of the hyobranchial apparatus are primarily cartilaginous, but specimen TNHC 51179 displays a single patch of mineralization near the distal ends of each of the first ceratobranchials. The expanded posterior portion of the second basibranchial is largely ossified in specimen TNHC 51179 (although the lateral tips are unossified); it remains cartilaginous in TNHC 51178. This structure is triradiate and asymmetrical in both specimens, and a median notch is particularly pronounced in TNHC 51179. In both specimens, the posterior (median) projection of the second basibranchial appears to be a separate unit. Both specimens exhibit the characteristic 16 presacral vertebrae. The vertebrae lack alar processes on the parapophyses, and the diapophyses extend well beyond the lateral margins of the zygapophyses throughout the vertebral column. The car-

pals and tarsals are cartilaginous; in TNHC 51179, eight carpals and nine tarsals are present (these are poorly stained in specimen TNHC 51178). Phalangeal formulae are: 1-2-3-2 (hand) and 1-2-3-3-2 (foot).

Morphometric analysis.—*Eurycea sosorum* was readily diagnosable based on the discriminant function analysis (DFA). Most of the discrimination between *E. sosorum* and the other groups included in the DFA occurred along the first canonical variate axis (Fig. 4), whereas discrimination that was possible among the other populations and taxa occurred primarily along the second or higher canonical axes. For this reason, we present details of the relevant axis (CV1) only; morphometric discrimination among other Texas *Eurycea* will be addressed elsewhere. The first canonical variate (CV1) accounted for 73.3% of the total discrimination among groups in the analysis and was influenced most strongly by eye diameter (95.3% of the variance of the measure), anterior limb length (79.9%), and hind limb length (63.4%). Overall size (as measured by SL) contributed relatively little to CV1 (10.2%). The two limb length measures had positive loadings on CV1, whereas eye diameter had a negative loading on CV1. Thus, the high scores along this axis for *E. sosorum* largely reflect the relatively long limbs and small eyes of this species compared to others. In fact, a bivariate plot of eye diameter versus standard length readily separates *E. sosorum* from the other species (Fig. 2). CV1 can be defined as:

$$\begin{aligned} \text{CV1} = & 8.471 \text{ SL} + 10.100 \text{ HLB} \\ & + 5.317 \text{ HLC} + 8.048 \text{ IOD} \\ & + 9.786 \text{ HLL} + 16.215 \text{ ALL} \\ & - 9.752 \text{ AG} - 2.992 \text{ TL} \\ & - 3.537 \text{ HLA} - 11.347 \text{ HW} \\ & - 54.874 \text{ ED} - 5.746, \end{aligned}$$

where for each measure X, $\log_{10}(X + 1)$ is used.

Individual scores for *E. neotenes* on CV1 ranged from -3.430-0.977 ($\bar{x} = -0.911$, $SD = 0.964$); for *E. nana*, range = -3.693-0.356 ($\bar{x} = -1.887$, $SD = 1.061$); and for *E. sosorum*, range = 4.404-8.340 ($\bar{x} = 6.179$, $SD = 1.209$).

Based on Geisser classification probabilities (Geisser, 1977), all 23 specimens of

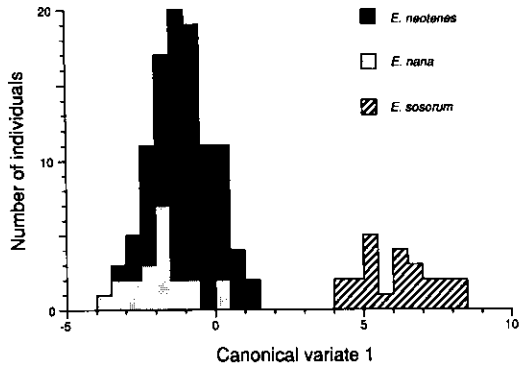


FIG. 4.—Distribution of specimens of *Eurycea neotenes* (dark shading), *E. nana* (light shading) and *E. sosorum* (crosshatching) along the first canonical variate of the discriminant function analysis. See text for details of CV1.

particularly among the populations currently assigned to *E. neotenes*).

These results are consistent with those of Sweet (1984), who included *E. sosorum* (which he called *Eurycea* sp. from Travis Co.) in a larger morphometric discriminant function analysis that involved both surface and cave-dwelling central Texas *Eurycea*. [Sweet also included meristic counts in his analyses that were not used in the present study.] Sweet's analyses showed that *E. sosorum* was readily discriminable from other central Texas *Eurycea*, with the exception of one individual (of 32) that was misclassified as *E. neotenes* in a posteriori tests.

E. sosorum were assigned to the correct group, and no individuals from any other populations were incorrectly assigned to the *E. sosorum* group (some misclassifications did occur among the other groups,

Distribution.—*Eurycea sosorum* is known only from the immediate vicinity of the outflows of two clusters of springs in Zilker Park in the City of Austin, Travis Co., Texas, collectively called Barton Springs (Figs. 5, 6). These springs flow throughout the year and maintain an approximately constant temperature of 20 C

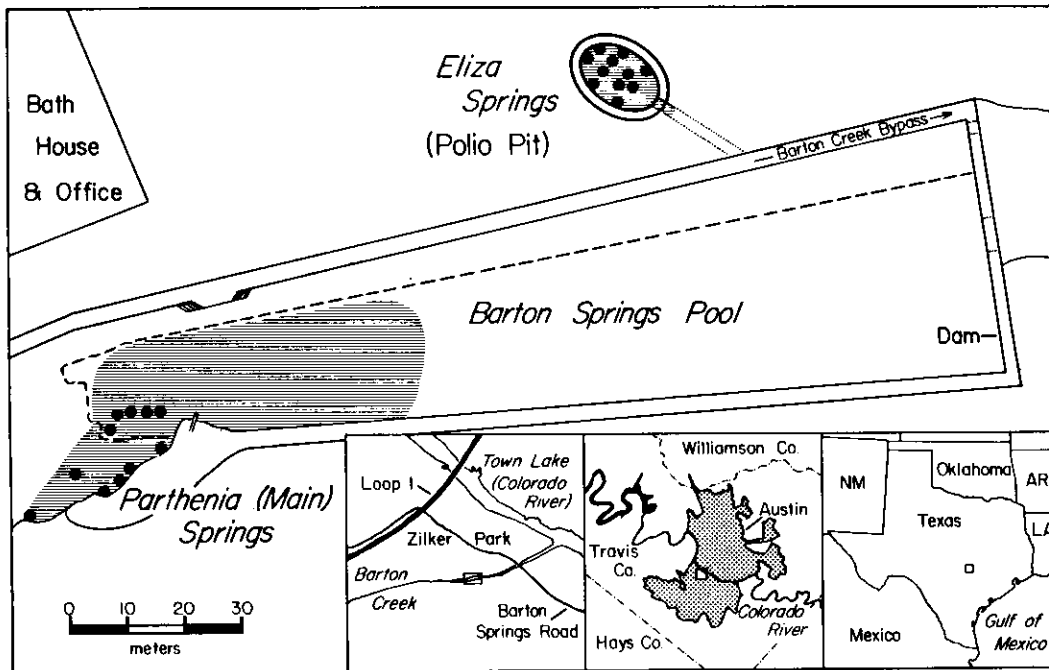


FIG. 5.—Known distribution of *Eurycea sosorum* and details of Barton Springs Pool and vicinity. Inset maps (from right to left) show: (1) location of Austin, Texas, (2) location of the Zilker Park area within Austin (the City of Austin is indicated by dark stippling), and (3) location of Barton Springs Pool along Barton Creek in Zilker Park. The main map shows the current surface distribution of *E. sosorum*, indicated by horizontal hatching. Solid dots mark spring outflows. The dashed line indicates the 1.5 m depth contour, which marks the approximate limits of the surface of the pool when it is lowered for cleaning purposes.

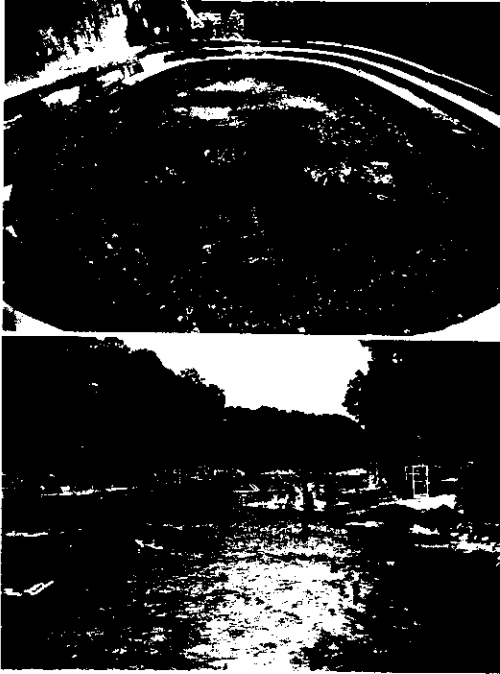


FIG. 6.—Upper photograph: Eliza outlet of Barton Springs, now modified to form a concrete pool of variable depth. Lower photograph: Barton Springs Swimming Pool, fed by the Parthenia Springs outlets (the main habitat for *E. sosorum*). The view is from the west end of the map in Fig. 5, looking east. Currently, the highest concentrations of *E. sosorum* occur at depths of about 3–5 m in the vicinity of the spring outlets, which are located in the middle and right foreground. The holotype was collected from a depth of about 4–5 m below the water's surface near the middle of the photograph. The projecting rock on which the diving board is located marks the approximate easternmost limit of spring outflows.

(Martyn-Baker et al., 1992). Most specimens of *E. sosorum* have been collected from a small (approximately 15 m diameter) wading pool fed by Eliza Springs and known locally as the Polio Pit, or Elks' Pit (Figs. 5, 6). An apparently larger population occurs in the area of the outflow of Parthenia Springs, which fill Barton Springs Pool (Figs. 5, 6). Sweet (1978) hypothesized that this species occurs in the aquifer from which the springs flow, and that individuals found on the surface have washed out of primarily subterranean habitat. However, recent evidence suggests that *E. sosorum* is predominantly a surface-dwelling species that has undergone a severe

reduction in available surface habitat over the last few decades (see Natural History and Reasons for Endangerment). Sweet (1978, 1984) regarded *E. sosorum* as unique among the central Texas perennibranchiate *Eurycea* in its possession of features that he interpreted as intermediate between those exhibited by epigeal (= surface-dwelling) members of the group, and cave-dwellers, specifically body proportions, numbers of presacral vertebrae, coloration, and tooth counts. We note that in general Sweet's (1978, 1982, 1984) approach was to recognize a minimal number of species in the central Texas *Eurycea*, and he referred the vast majority of spring and cave populations to *E. neotenes*. However, he strongly advocated recognition of the Barton Springs population as a distinct species based on its unique morphology (Sweet, 1978, 1984).

The Barton Springs Aquifer is hydrologically distinct from other underground waters in central Texas; these waters are collectively called the Edwards Aquifer (for a non-technical summary, see Martyn-Baker et al., 1992; for details of the hydrology and geology of the region, refer to Slade et al., 1986). *Eurycea sosorum* is the only species of *Eurycea* known from the Barton Springs Aquifer and its spring outflows. This species has not been found in other springs and caves that are fed by or intersect the Barton Springs Aquifer (personal observations; W. H. Russell and J. R. Reddell, personal communications to P. Chippindale). This further suggests that the species is restricted to the immediate vicinity of Barton Springs, and is unlikely to range extensively underground.

Natural history.—Few details of the biology of this species are known. Recently hatched young have been found in November, March, and April, and females with well-developed eggs have been found in September through January. One female retained well-developed eggs for over a year in captivity. Recently captured specimens contain the remains of amphipods in their stomachs, and captive specimens feed on amphipods, earthworms, whiteworms, brine shrimp, and commercial fish food pellets. At present, specimens

are usually found under rocks or in gravel in about 0.1–5 m of water, but *E. sosorum* will also take refuge among aquatic vascular plants and algae when such habitat is available. In this respect, the behavior of this species is very similar to that of *E. nana* at San Marcos Springs, Hays Co. Our observations, and the evidence cited below (see Reasons for Endangerment), indicate that *E. sosorum* makes extensive use of surface spring habitat when given the opportunity. This species clearly is capable of living underground, and as Sweet (1978, 1984, personal communication) has emphasized, it shows several morphological features that are associated with subterranean living in other members of the *E. neotenes* species group. We suspect that *E. sosorum* is predominantly a surface-dweller that also is able to live underground.

Using SCUBA equipment, relatively large numbers of *E. sosorum* can be observed; for example, on 24 November 1992 we (P. Chippindale and D. Hillis) counted at least 150 individuals during a 2-h dive in Barton Springs Pool. Thus, prospects for more thorough, long-term studies of this species in the field are excellent, provided that habitat and water quality can be maintained.

Reasons for endangerment.—Prior to 1989, aquatic vascular plants were abundant in Barton Springs Pool. According to field notes, some of the first specimens of this species were collected from among plants in Barton Springs in 1946 by Bryce C. Brown and Alvin Flury (BCB 1879–1885 and TNHC 6317–6321; the BCB specimens have been destroyed, although the field tags remain at the Strecker Museum, Baylor University). They apparently were abundant at the Eliza Springs outlet as recently as the early 1970's, when "dozens or hundreds" could be found at a time by searching through submerged leaves (J. R. Reddell, personal communication to P. Chippindale). In contrast, in surveys of Eliza Springs between 1987 and 1992, we rarely found more than one or two individuals, and often found none. In 1992, City of Austin staff agreed to stop cleaning the outlet at Eliza Springs, and

the habitat at that location has rapidly improved. Bottom sediments and vascular plants have become established, and the salamander population has increased substantially; 15 individuals were observed during a SCUBA survey on 16 November 1992. Prior to October 1992, City of Austin employees partially drained Barton Springs Pool as often as twice per week, used chlorine to clean the shallow end and side walls, and used high-pressure fire hoses to wash silt and loose algae from the shallow end into the spring outflows. Following a chlorine-induced vertebrate kill in Barton Springs on 28 September 1992, individuals of *E. sosorum* could be located only around the immediate outflow of the largest of the Parthenia Springs openings (during a SCUBA survey on 1 October 1992). After this date, city employees stopped using chlorine to clean Barton Springs Pool, a volunteer-assisted manual cleaning effort was initiated, and waste water from the shallow end was diverted from the spring openings. The habitat in the pool has improved rapidly since that time; vascular plants have begun to re-establish themselves and *E. sosorum* appears to be rapidly re-expanding its range in the pool. We currently are monitoring the status of the surface population of *E. sosorum* using SCUBA surveys. We also are working closely with City of Austin staff and representatives of state and federal agencies to help develop maintenance procedures that are compatible with the survival of *E. sosorum* and the continued use of Barton Springs by humans. This will be accompanied by an education campaign to inform the public about the Barton Springs salamander and the ecosystem that exists in the pool.

The new maintenance practices at Barton Springs Pool appear to be suitable for maintenance of a healthy population of *E. sosorum*. We see no conflict between human use of the pool for swimming and the continued existence of this species. Indeed, many Austinites have adopted *E. sosorum* as a symbol of water quality and the uniqueness of Barton Springs, and the salamander is even depicted on a popular T-shirt. Additional threats to the species

include urban runoff, increased development in the Barton Creek watershed, and the risk of a catastrophic toxic chemical spill or sewer line breakage in the urban zone surrounding Barton Springs. The Barton Springs Aquifer has been designated by the Texas Water Commission as one of the aquifers most vulnerable to pollution in Texas.

Eurycea sosorum has been listed (as the Barton Springs salamander, *Eurycea* sp.) by the U.S. Fish and Wildlife Service as a candidate for federal protection (Category 2) under the Endangered Species Act since 1982 (Federal Register 1989, 54:558). Recently, M. Kirkpatrick and B. Mahler petitioned for its listing as a federally Endangered Species (in two petitions; one submitted in January 1992 and the other, requesting emergency listing, submitted in November 1992). The initial petition has been ruled valid by the USFWS (Federal Register 1992, 57:58779–58781), and at the time of writing the USFWS is further investigating the basis for listing of this species. *Eurycea sosorum* appears to have one of the smallest ranges of any vertebrate in North America, occurs in an area of extreme environmental sensitivity, and is highly vulnerable to extinction.

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APPENDIX I

Specimens Examined for Morphometric Variation

Eurycea neotenes: Bexar Co.: Helotes Creek Spring (type locality): MVZ 120043-46, 120048, 120051-54, 120056, 120068, 120076, 120079, 120085-86, 120090-93. Blanco Co.: Boardhouse Spring: TNHC 51121-27. Comal Co.: Comal Springs: MVZ 120392, 120407, 120415, 120419, 120424, 120427-28, 120430-32, 120434, 120445-46, 120448-50; TNHC 51052-53,

51056. Hays Co.: Fern Bank Spring: TNHC series 31004, informally tagged as specimens 2, 3, 5, 6-8, 10-12, U1, U3-6, and X; TNHC 51104, 51106-07, 51112. Kendall Co.: Cibolo Creek Tributary Spring: MVZ 121234, 121240-41, 121243, 121245, 121248-49, 121253, 121255, 121257-58, 121260-262, 121266, 121269, 121279, 121282, 121287.

E. nana: Hays Co.: San Marcos Springs: TNHC series 50901, informally tagged as specimens 1-3, 4-6, and 8-9; TNHC series 21661, informally tagged as specimens 1-9; TNHC 46289-290, 46292, 46294.

E. sosorum: Travis Co.: Barton Springs (Eliza and Parthenia outlets): MVZ 122712-716, 122718; TNHC 50915-18, 50920-21, 50923-25, 50928, 50931-32, 51180, 51183-86.

Note Added in Press

In January 1993, *Eurycea sosorum* was found in the outflow of the Sunken Gardens Springs, also known as Old Mill or Walsh Springs (Brune, 1981). These springs are part of the Barton Springs group and are located approximately 300 m east of the main (Parthenia) springs.